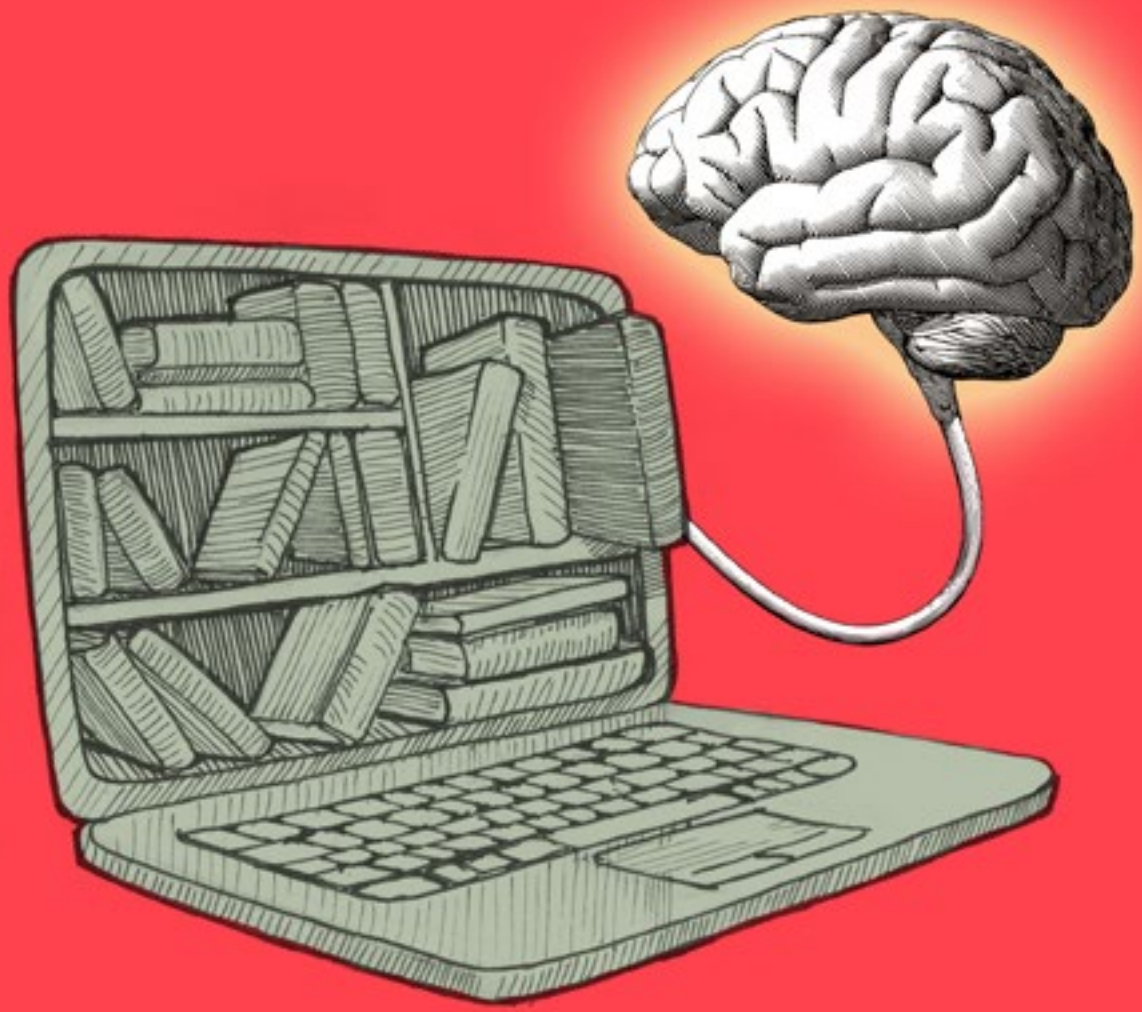
THE COMPLETE GUIDE TO MEMORY

The Science Behind Remembering Anything

by Scott Young & Jakub Jílek



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How does your memory work? How can you remember more? Prevent forgetting?

These questions lie at the heart of anything you'll ever learn, do or experience. Your memory impacts everything you do, from how well you'll do in school, your career, life and even your sense of self and happiness.

This is a topic that has long fascinated me, and I've written a lot about memory previously on this blog. However, I wanted to create a guide that would combine and integrate everything we know scientifically about memory, and distill that knowledge into practical advice.

To do that I collaborated with Jakub Jílek, who has his masters in cognitive science at University College London, and is currently studying for his PhD. In this complete guide, we will cover everything you need to know about memory, how it works and how you can improve it.

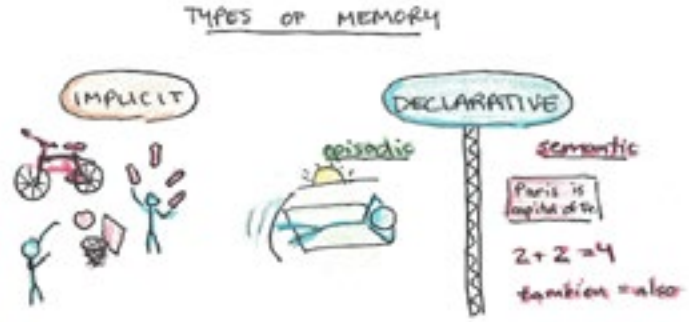
Why Memory Matters

What is memory? The general consensus is that memory is a multitude of cognitive systems which allow us to store information for certain periods of time so that we can learn from our past experiences and predict the future.

Memory impacts every facet of our lives. The first step to remembering things better is to understand how your memory works.

There are two basic kinds of memory – retrospective and prospective. Whereas retrospective memory is about remembering what happened in the past, prospective memory is about reminding yourself to do something in the future. Without prospective memory, you would not remember to go to work in the morning and you would forget to set your alarm clock in the evening.

One way to divide up retrospective memory is in the kinds of things it stores. A big difference here is between implicit and declarative memory.



Implicit memory is essentially skill memory – the ability to do a task. If your implicit memory failed, you would not be able to brush your teeth, take a shower, drive your car or ride a bike. This kind of memory shows up in our abilities, but we can't always articulate what it is we know in words and concepts.

Declarative memory, in contrast, is either memory for facts and meaning (semantic) or memory for events (episodic). Without semantic memory, you would not understand the content of what your colleagues or friends were saying. Without episodic memory, you would struggle to recount your day later to someone else.

Another way to examine memory is based on its duration. Working memory (WM) manipulates and stores information for short periods of time. Talking with your colleagues, discussing a point at a meeting and planning your weekend would be entirely impossible without WM. In contrast, long-term memory (LTM) serves as a long-term storage of information. Almost all of our everyday activities depend on LTM, such as remembering our way home or how to drive a car.

Here's a quick recap of the different types of memory:

- **Retrospective Memory** — Remembering the past
  - **...by Content**
    - **Declarative / Explicit**
      - *Semantic* — Memory of facts and meaning
      - *Episodic* — Experiences you've had
  - **...by Duration**
    - **Working Memory** – What you can "keep in mind" at the same time, to think, reason and solve problems.
    - **Long-term Memory** – Anything you remember longer than a moment–what you ate for breakfast, exam questions or your friend's birthday.
- **Prospective Memory** — Reminding yourself to do something in the future

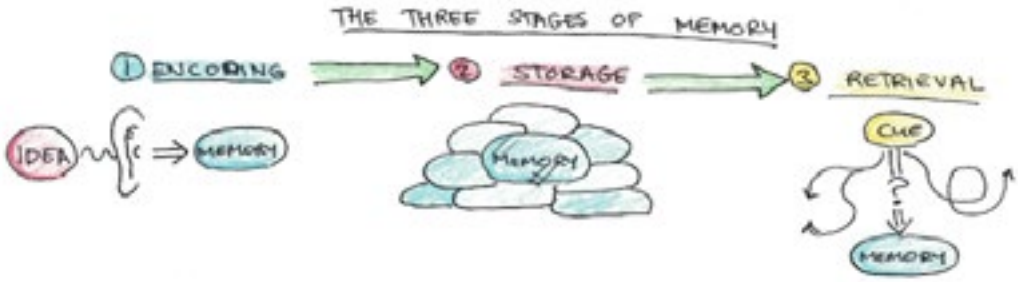
In this guide, we're going to focus mostly on declarative, semantic memories. This is covers most of the things you're trying to "remember", like facts, dates, names and ideas.

The Three Parts Underlying All Your Memories

What does a ten-dollar bill look like (or a common banknote, if you're not American)? Do you think you'd be able to draw one? Although we see coins and banknotes on a regular basis and therefore have virtually limitless opportunities to learn their shape, few people could sketch one accurately. Looking at something repetitively does not guarantee that we will remember it later. Why can't we draw a ten-dollar bill, yet we could recognize it instantly if we saw one?

To unravel this mystery, we need to break the act of remembering things into its atomic parts. Those parts are:

1. **Encoding**—the process of putting the information into your brain.
2. **Storage**—the process of keeping the information in your brain.
3. **Retrieval**—the process of getting the information out of your brain when you need it.



Understanding these three functions is essential if you want to have a better memory. Any attempt to improve your memory must either encode

the information better (or in a format you're more likely to retrieve), store the information better and longer, or retrieve it in the situation you need.

Let's look at all three and see how we might be able to improve our memories.

Encoding: Putting memories into the brain

Encoding is a process of imprinting information into the brain. Without proper encoding, there is nothing to store and attempting to retrieve the memory later will fail. One way to improve encoding is simply to repeat the information more times. Scientists who study memory call these repetitions "rehearsals" of the information.

However, as the case with the bank note illustrates, many rehearsals do not always mean you'll successfully recall the information. What makes the difference between this case and the more familiar case of remembering your phone number because you've had to use it a lot?

When you were trying to memorize the phone number, you did not merely look at it repetitively. Instead, you deliberately tried to memorize it. You may have read it to yourself several times. Maybe you attempted to recall it from your memory, checked whether you were right and corrected yourself accordingly. Perhaps you noticed that there were some relationships between different numbers (e.g. some numbers were the multiples or sums of preceding or following numbers). In summary, you employed certain cognitive strategies and processes. You still needed repetition, but repetition was effective only when used together with these strategies.

Similarly, if you want to have an effective memory, the cognitive strategies you use will make a big difference on your ability to remember things later.

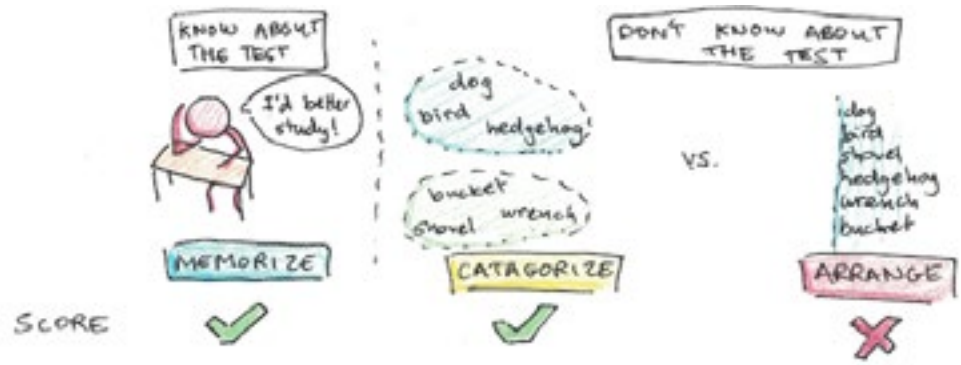
What kind of encoding strategies are most effective?

Intention to learn: Does it matter how much you want to remember?

In an intriguing study, scientists asked students to study lists of words.[1] One group was explicitly told to memorize the words (with a warning that there would be a test later), whereas the other two groups were asked to either sort the words into categories or to simply arrange them into columns (unaware that there would be a test later).

One would expect that the students who deliberately studied the words would perform better than the categorizing and arranging groups, who

did not make such effort. However, this was not the case. The categorizing and memorizing groups performed equally well in the test, whereas the arranging group performed worse than the other two groups.



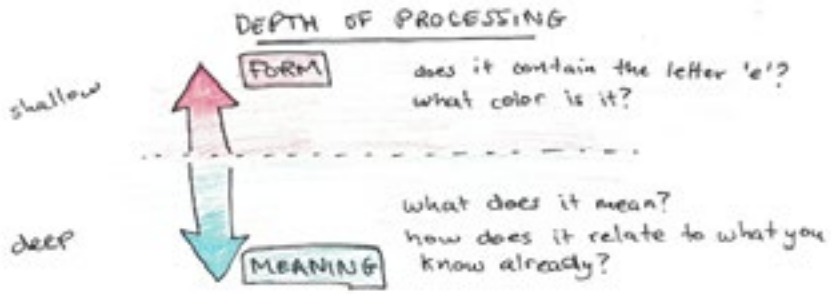
Why didn't the students intention to learn make much difference?

In brief, the researchers found that the students who were told to memorize categorized the words in the same way as the students who were explicitly told to do so. By categorizing, the two groups effectively processed the words more deeply than the students who simply arranged them. As a result, they encoded the words more strongly than the arranging group and achieved better test results.

This experiment shows that the mere intention to learn something is not what makes you remember it later. What matters is what you do with the material, i.e. what specific strategies you use to process it, rather than how much you want to memorize it.
Let us take a look at these strategies.

Depth of Processing: Why how you process information determines how much you'll remember later

Scientists believe that one of the critical factors determining the success of encoding is the depth of processing. The deeper you process the to-be-learnt information, the more likely it is to stick. What exactly is 'deep' processing?



In essence, deep processing focuses on the meaning of the information.

Try this demonstration:[2] Read the following list of words 3 times. After you have read the list, try to recall as many words as possible, minimizing your window or otherwise covering up the words on the screen:

cabbage, table, river, shirt, gun, square, iron, dentist, sparrow, mountain, hand, granite

How many words did you remember? Now try the same thing with another list:

pink, green, blue, purple, apple, cherry, lemon, plum, lion, zebra, cow, rabbit

How many words did you remember? Try it once more with the following list:

thread, pin, eye, sewing, sharp, point, prick, thimble, haystack, thorn, hurt, injection

How many words did you remember now? It is quite likely that you remembered most items from the second and third lists and the fewest items from the first list. As you may have noticed, the second list consists of items grouped into categories (color, fruit and animal), whereas the third list contains items which are related to the word 'needle'. In contrast, the first list consists of completely unrelated items.

The reason why it was easier to memorize items from the latter two lists is that the items were meaningfully connected – they were subjectively (consciously or unconsciously) organized into a specific category or related to a common concept. Giving meaning to information is beneficial as it harnesses the process of spreading activation (which we'll cover in the section on "Spreading activation").

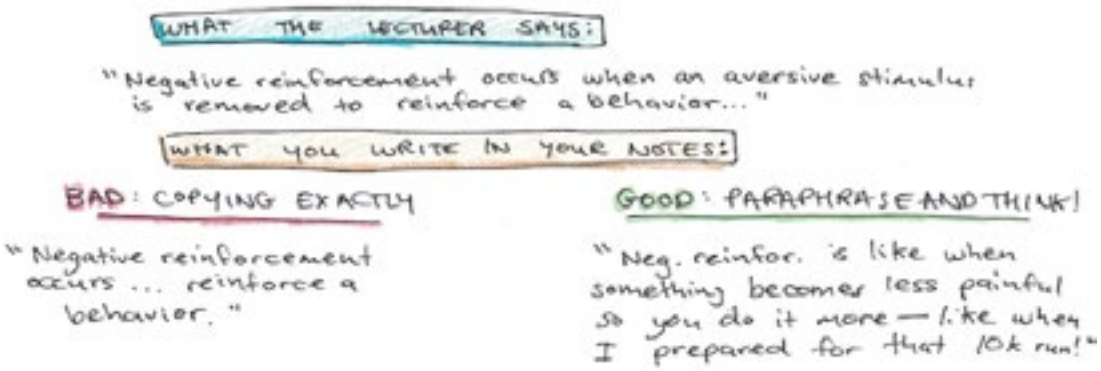
The main implication of this study is that structured information is much easier to encode to memory than disorganized information.[3]

Therefore, it is extremely useful to impose a good structure on your notes. The structure can take many different shapes – hierarchical, flow-based, mind-mapping or anything else that you find useful. What matters is that the particular technique helps you organize the study material in an easy, clear and understandable way. (we will cover these note-taking techniques in detail in a separate article on learning)

Categorization and structuring are not the only ways that you can give meaning to information. A powerful technique that substantially improves memorization is **self-explanation**.[4] Self-explanation simply consists of asking yourself questions about the study material as you study:

- How does this concept related to the other?
- What are the implications of this concept for...?
- Why does it make sense that...?
- What are the steps that I must take to solve this problem?

A very effective way to make yourself process information deeply is to explain the study material in your own words. If you are to explain a concept using different words than those used by the textbook or the lecturer, you firstly have to process and understand its meaning and logical connections with other concepts, which effectively boosts encoding by stimulating deep processing. This stands in stark contrast with the situation where you simply re-read the textbook or lecture notes, which constitutes only superficial processing and does not lead to effective encoding.



When taking notes, make sure that you do not copy the words of your textbook and lecturer verbatim. Instead, try to use your own words as much as possible. Researchers have shown that typing notes on a computer encourages copying information verbatim (even if students are explicitly instructed to use their own words), unlike writing notes by hand. As a consequence, students who take notes on a computer underperform in tests compared to students using handwriting.[5]

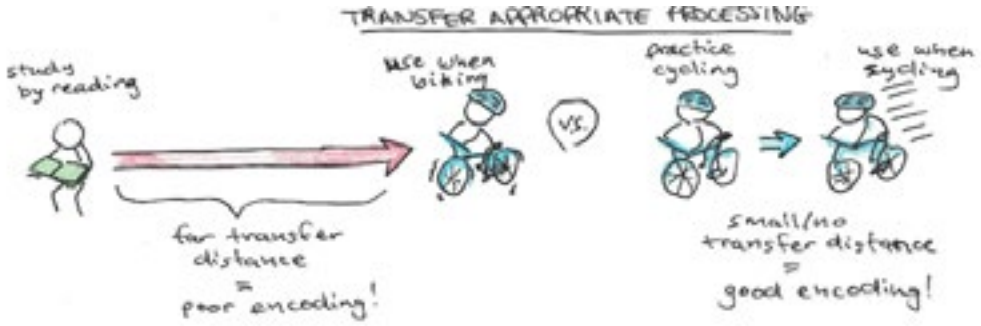
Our general recommendations are the following

- Take structured notes (whatever suits you best: hierarchical, flow-based, mind-maps, etc.)
- Do not memorize lecturer's or textbook phrases, explain concepts to yourself in your own words
- When taking notes, avoid copying information word-for-word. Use your own phrasing instead.
- Avoid taking notes on a computer. Take handwritten notes instead.

Transfer-appropriate processing: The trick to acing your exams

Imagine yourself learning how to ride a bike. You could buy a 200-page long book on cycling and memorize everything perfectly. If you were to sit a written test, you would ace it.

Now imagine that you were to actually ride your bike. What do you think would happen? The chances are that you would crash as soon as you got on your bike.

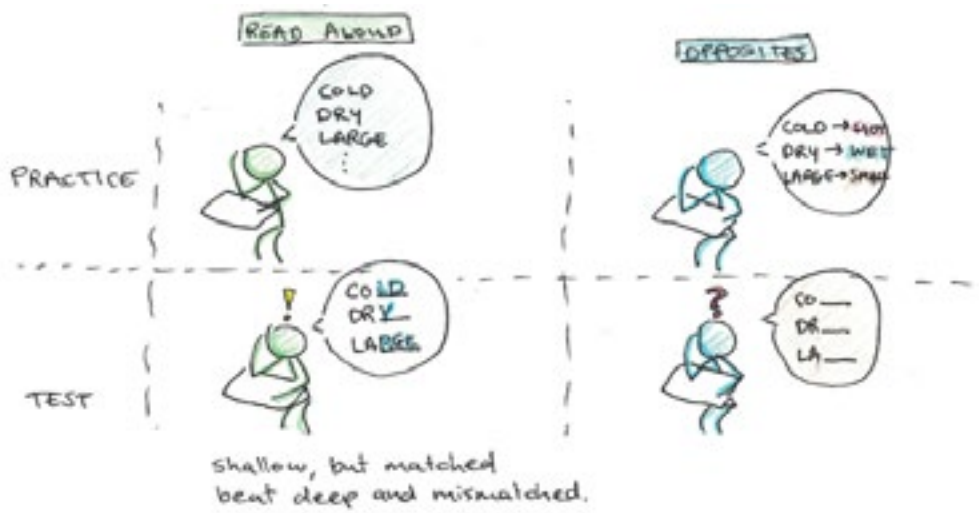


Although you knew everything you could about cycling, a key element was missing. The reason for the crash is that the cognitive processes used during during encoding did not match (=transfer appropriately to) the processes needed during retrieval. **To remember effectively, the processes used during practice need to correspond with the processes during use.**

As an illustration, consider the following study:[6]

Researchers asked students to either read aloud a list of words (superficial processing), or to generate these words from their antonyms (deep processing). The students were later asked which words they could remember (free-recall) or to fill in missing letters in words (fragment completion).

One would expect that the superficially-processing students would underperform in both tests (because deep processing is generally better than superficial processing – see previous section). However, this was the case only for the free-recall test. Surprisingly, in fragment completion, the superficial-processing group was better than the deep-processing group.



What could explain this surprising result?

The reading group processed the words perceptually, while the generating group processed them semantically – they had to retrieve from memory words with a particular meaning. Whereas perceptual processing matched the processing needed by the perceptual task, semantic processing matched the processing needed during recall (note that words are stored in semantic memory based on their meaning).

The main implication of this study is that although deep processing is extremely beneficial for memory, it may not be enough to fully optimize your test performance. To further improve your results, it is important that you practice with similar processing that will be required during the test.

Think hard about how you will be tested on the information you need to remember. Will it be multiple choice tests? Essay questions? Applied in real life problems? Then make your practice match the situation where you use it. Mismatched practice is a major cause of poor memories–they simply aren't encoded in a way that is useful.

If your exam will consist of writing an essay, an excellent strategy is to do

your reading with pre-reading questions.[7] Pre-reading questions force you look for arguments and evidence in order to answer the questions, which are precisely the processes that you will need during your essay-type exam.

However, it turns out that transfer-appropriate processing is only one consideration that matters for memory. This is because some encoding strategies are generally better than others, regardless of whether they match the test format or not. In fact, one specific encoding strategy dominates almost all other strategies. This strategy is called "recall" and is discussed later.

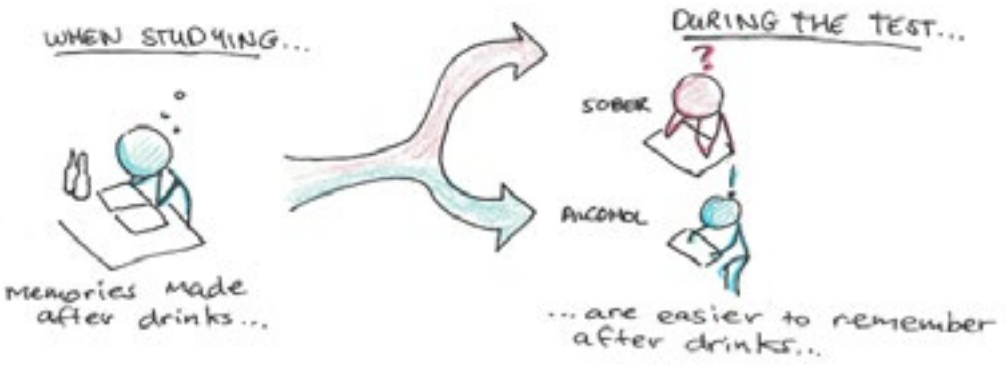
In summary, if you are going to take a test of a particular format (such as an essay format), the best approach is to reap the benefits of multiple strategies. Whereas practicing with the final test format will teach you to processes the material in the way required by the test, recall will lead to most effective encoding. Therefore, ideally you should:

- Spend about 1/4 of your time practicing with the final test format (e.g. multiple choice)
- Spend the remaining 3/4 practicing with recall combined with deep-processing techniques

State-dependence: How your physical/mental states drive your memory

Imagine the following scenario: You have to prepare for tomorrow's test but your friend has a birthday party tonight. You decide to go to the party and end up having a few alcoholic drinks. When you come back home, you are quite drunk but you study for the test anyway. The next morning you go to school to sit the test. Would you be better off taking a shot or two of an alcoholic beverage before the test or is it a better idea to refrain from drinking any more alcohol?

Setting aside the fact that you would likely not be admitted to school in a drunk state, science has an astonishing answer: **In order to improve your performance, you should top up alcohol to approximately the same level you had during revision** (this was actually shown in a study[8]).



What could explain this surprising result?

Research has show that our memories are state-dependent. The more similar are our mental, physical and chemical states between encoding and retrieval, the more likely we are to successfully remember. Memory relies on a chemical process through which new connections (pathways) are formed and strengthened between neurons. If you study in a particular state, the memory trace is encoded with brain activity influenced by this state and becomes to some degree dependent on its reinstatement.

State-dependence of memory has been found for all kinds of drugs and medications, including nicotine[9], caffeine[10], cannabis[11], Ritalin[12] or anti-histamines[13]. If you are on medications such as Ritalin, it is therefore a good idea to keep the same dose during both revision and testing. If you cannot drink coffee or smoke cigarettes while you are taking a test, you had better avoid these drugs during revision as well. Moreover, it is important to realize that, the majority of drugs have well-known detrimental effects on memory, especially alcohol[14] and cannabis[12]. You stand the best chance of passing your test if you both revise and take the test while you are sober.

State-dependence of memory applies to other states as well. If you study in a good mood, you are likely to perform better in a test if you are also in a good mood (and the same applies to other moods)[15]. Similarly, if you study while standing up/doing aerobic exercise, you are more likely to remember the material if you are also tested while standing up/doing aerobic exercise[16].

One approach to overcome state-dependence of memory is to try to study in the same state that you will be in during the exam. You could, for instance, revise sitting at a desk, while simulating stressful feelings (e.g. by timing your answers), assuming that these conditions will be the same during the exam.

However, this is not always possible. An alternative approach is to study in various mental and physical states. The logic behind this is that you never know what kind state you will be in during your exam therefore it is best to make your memory independent of any particular states. For example, you could revise both when you have a lot of energy and when you are low on energy. Also, it is a good idea to study regardless of the mood you are currently in.

In summary:

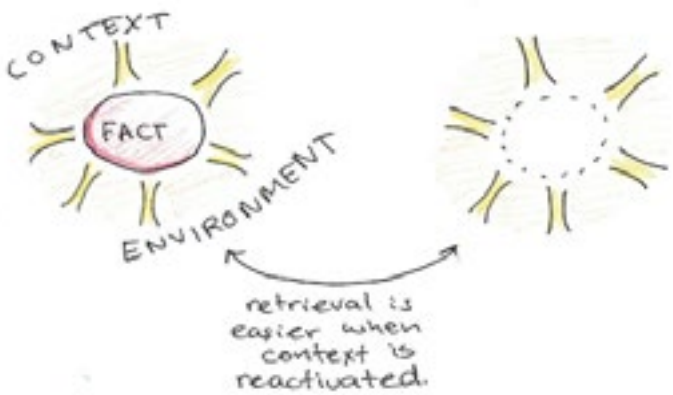
- Spend at least 1/4 of your study time simulating the state you will likely be in during your exam (e.g. sit at a desk, time your answers)
- Study regardless of your mental/physical state (in different moods, with different energy levels, etc.)

Context-dependence: Why your environment matters

Consider an everyday situation: You get up from your desk to have a cup of tea. Once you arrive in the kitchen, you forget what you wanted. However, when you get back to your desk, you suddenly remember.

Scientists have discovered that memories are heavily context-dependent. Context is essentially anything that is present during encoding (for instance the environment we are in). **Our brains seem to encode the context as a part of the memory trace as if taking a snapshot of everything that is around us at the moment of creating the memory.**

Successful retrieval of the memory trace then depends to some degree on the re-activation of the context in which it was encoded. Since the intention to have a cup of tea was encoded with the context of the kitchen, coming back to the kitchen re-activated the intention to have a cup of tea.



To combat context-dependence, you can adopt the same two approaches used for overcoming state-dependence. The first approach would be to emulate the environmental context of the test. For instance, you could revise in a quiet/noisy environment depending on where your exam will be situated. You may also consider revising together with a friend or two to get used to being distracted by other people in the examination room. An even better idea would be to revise in the classroom where you will be taking the test.

The second approach would be to revise in as many different contexts as possible. Studies have shown that students who revise in many different rooms prior to their test perform better than those who study in one room only (with a 30% improvement in test performance)[17].

Since the environmental context keeps changing, the information effectively becomes context-independent. In other words, you teach yourself how to retrieve the studied material in any kind of circumstance, which is extremely useful given that fact that you often cannot predict the exact circumstances you will face during the exam.

The context of study need not be only environmental. The particular questions and practice tests you use also become the context that is encoded with your study material. Therefore, the more questions you practice on for a given concept, the more neural connections the brain has to generate between different contexts and the target concept. The more routes the brain has built, the easier it is to retrieve the concept later. This is because retrieval becomes less dependent on the particular starting point – the type of question asked or its particular wording.

The impact of this kind of context-sensitivity is particularly important when creating flashcards. If the question side of your flashcard contains irrelevant information, or information that won't be present when you really need to remember, you may not be able to recall it when you need it.

Consider the following flashcards:

Q: How do you say "again" in Chinese, but only for actions that you will repeat in the future? Like asking someone to do repeat something they just said...
A: 再

Compare that to:

Q: Again (future)
A: 再

The former has so much more context, that you may memorize the pairing only with this context (which may be missing when you need to think about the term).

For this reason, it is better to either ask yourself questions with as little context as possible (and thus maximum difficulty) or to ask many different questions, with different contexts, so the same context isn't required for successful retrieval.

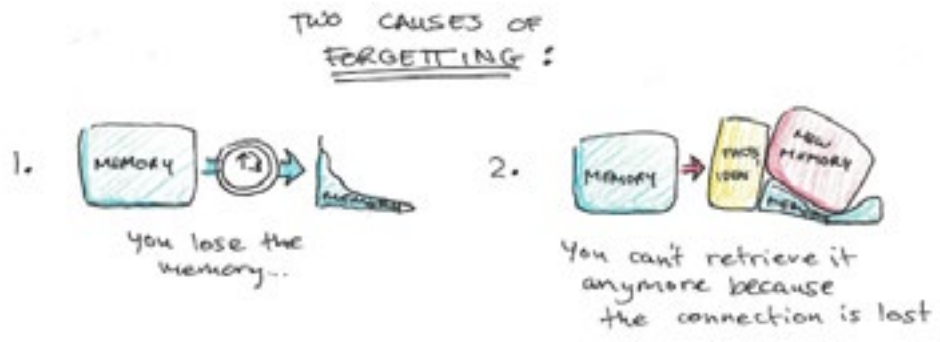
In summary, we recommend the following:

- For 1/2 of your study time, simulate the environmental conditions of your test (a noisy/quiet environment, similar distractions, people around)
- For the other 1/2, alternate rooms, places and conditions as you study
- Test yourself with different kinds of practice questions
  - what-questions
  - why-questions
  - how-questions
- Make use of minimal context for flashcards, or if possible, try different ways of asking yourself questions to maximize your flexibility.

Storage: Keeping memories in the brain

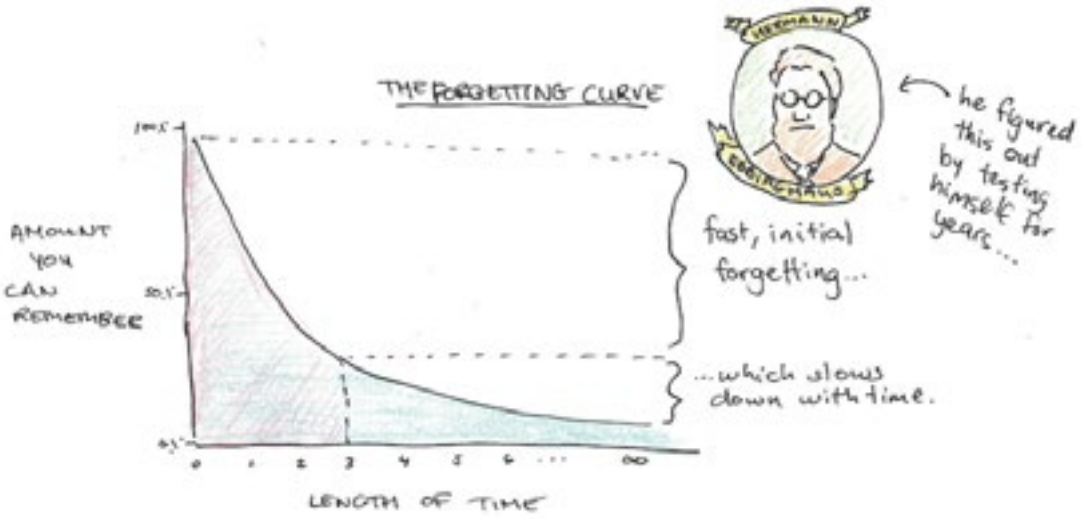
Once you've encoded information, you now need to store it. Unfortunately, forgetting is a major part of how our brains work. Most of us can't remember what we had for dinner Tuesday, three weeks ago. However, we can all remember our first kiss.

Forgetting can be caused by two different processes. The first is a **failure of storage**—the information might be forgotten because our brain loses it over time. The second is a **failure of retrieval**—the information might be "in" there, but we can't access it. Experimentally, it's very difficult to tell these two apart, but since they are separate processes, we'll consider each separately as we look at how memory works.



The progression of forgetting was originally studied by the famous experimental psychologist Hermann Ebbinghaus. Ebbinghaus discovered that forgetting follows an exponential decay function. Whereas in the first hours after study there is a rapid drop in the number of items successfully remembered, there is relatively little forgetting from the 2nd day onwards.

Although the exact shape of the forgetting curve is likely individual and depends on many factors related to the study material (e.g. how easy/difficult/interesting the material is or how well it was encoded), it approximates an exponential curve, with rapid forgetting in the beginning and less forgetting in later periods of time.



Why do we forget information in the first place? What can we do counteract the process of forgetting?

Trace decay: Do your memories fade with time?

The most basic explanation of forgetting has to do with the passage of time. Our memory traces are stored in living tissue, which inevitably changes over time. It is a well-known fact that connections between neurons deteriorate over time and as a consequence, the memory traces stored within these connections decay.

In addition, there is another possible cause for the decay of our memories. Surprisingly, making new memories may be part of the reason we forget. As new memories are formed, new neurons are produced in the

hippocampus (the memory hub), which changes its structure and patterns of connections.[18] As a consequence, older memories are more difficult to retrieve.

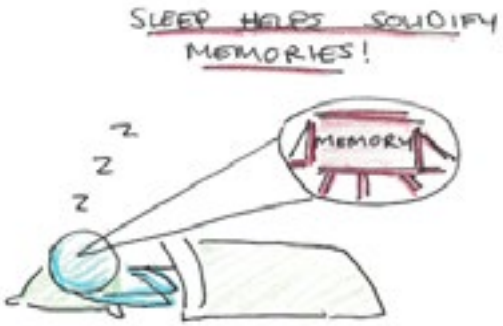
Therefore, if you need to retain old information in memory (for a final exam for instance), it would be a good idea to revise it again while you are studying something new, otherwise the old information might be superseded by the new information.

We recommend that you establish a schedule of revision of the old material (even a couple of minutes every day should suffice) that is interspersed with the study of the new material. This is especially important if you study several different subjects/topics within one day because you memory cannot yet benefit from protective sleep-induced consolidation processes. There is another reason why studying new things can impair the retrieval of old things and we discuss it in the section "interference".

In summary, we recommend the following

- Spend about 1/10 of your study time revising old material
- Insert brief periods of revision of old material into the study of new material

Consolidation and sleep: Let biology do the work for you



Learning does not finish with the end of studying. For a memory trace to become permanently established in our long-term storage systems, structural biological changes must take place in brain tissue. New connections between neurons must be formed and firmly established.

These changes are not immediate and take time. In scientific terms, the mechanism through which recent memories become permanent memories is called 'consolidation'. **Although some consolidation occurs during wakefulness, the primary time for consolidation is sleep.**

Have you ever studied for an exam through the night? If so, did you perform as well as in other exams for which you enjoyed a full night of undisturbed sleep? Probably not. Unsurprisingly, researchers have found that sleep deprivation impairs memory consolidation and undermines learning.[19] In fact, sleep deprivation (before or after learning) can worsen performance in a declarative memory test by as much as 20-50%[20][21]. Moreover, prolonged sleep deprivation has permanent damaging effects on memory.[22]

On the other hand, you can use sleep as a powerful aid in-between your study sessions. You may have heard of 'power naps' – short periods of sleep used to refresh energy. **There is now robust evidence to recommend naps.**[23] Napping during the day will protect your memory from trace decay (see section 'Trace decay') and interference (see section "Interference") due to sleep-induced consolidation processes. In other words, you will forget less of the subject studied than if you stayed awake for the same amount of time.

If you decide to give napping a try, it is important to be aware of the different stages of sleep. Napping for the maximum of 20 minutes is effective for restoring your energy, however, it is not enough to reach deeper stages of sleep during which consolidation occurs.

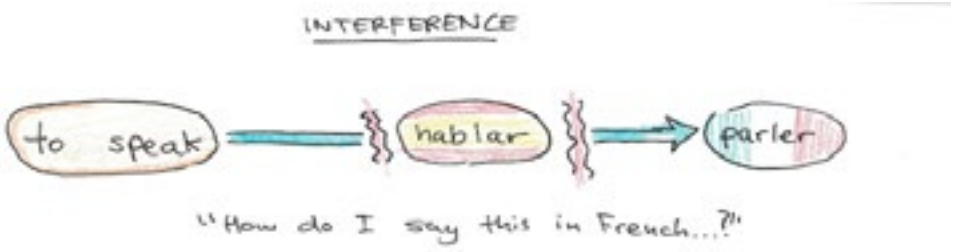
In order to boost your memory, you need to sleep for at least 60 minutes. However, napping for 60 minutes has the downside of leaving you in a

groggy state for about 30 minutes afterward (because you wake up in the middle of deep sleep). Therefore, it is best to sleep for a full 90 minute cycle. After that, you will both feel refreshed and your memory will benefit from consolidation. Another good option that has been found to be effective is to schedule your study session to the evening right before sleep.

In summary, we recommend the following:

- Take a 20-minute nap to restore your energy.
- Take a 90-minute nap after a study session to consolidate your memory.
- Schedule your study sessions before sleep to reap the full benefits of consolidation.

Interference: Does learning new things block your old memories?



Do you remember what you had for dinner two weeks ago? Now choose your favorite trip from a couple of years ago. How much do you remember from that trip? The chances are that you do not remember what you had for dinner but you do remember something about your trip, although it took place much earlier than the meal.

This example shows that **forgetting is not simply memories decaying with time.** Our memories crucially depend on cues. A cue is essentially anything (such as a physical object, situation, time period, word, question, concept, etc.) which is paired with a memory trace and which must be activated for the memory trace to be retrieved.

If we pair the same cues with multiple memory traces then it will be difficult to retrieve one particular trace because once the cue is activated, the activation will spread to all paired memory traces at once and these will compete for entry to consciousness.

Coming back to the example above, if you usually dine in the same place, many different meals will become associated with the same cues (the dining environment). Therefore, it will be hard to retrieve the specific meal that you enjoyed a week ago. In contrast, you probably have not been on the same trip many times before, therefore it is easier to remember its details because they context of the trip is not paired with any other memories.

The disruption of memories by other memories which are paired to the same cues is called "interference". You may have experienced interference yourself if you ever studied a second language. Interference may have caused you to be unable to retrieve vocabulary from one language. Instead, vocabulary from the other language popped to your mind. In this case, interference did not necessarily cause a loss of memory, but the memory trace became blocked thus temporarily inaccessible.

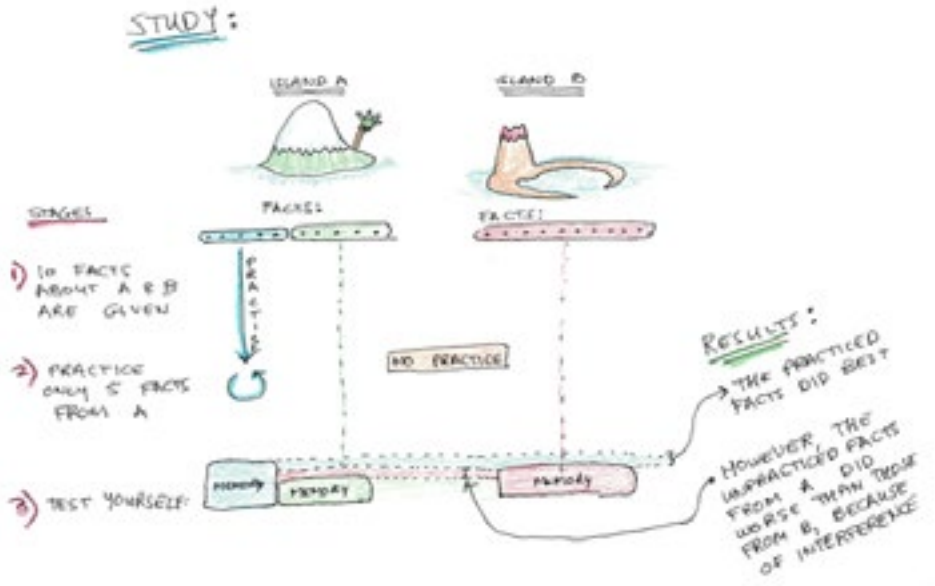
Research has found that the only way to overcome blocking interference is by making conscious effort to recover the correct memory trace (and have patience as this may take some time). Interference may, however, also cause a permanent loss of memory. Scientists who study memory call this the retrieval-induced forgetting effect (RIF).

As a demonstration, consider the following experiment: Students studied 10 geographical facts about each of 2 islands (A and B).[24] They subsequently practiced retrieving 5 out of 10 facts for island A. Afterwards, their knowledge of these facts was tested.

What do you think happened to students' memory about island A?

Unsurprisingly, retrieval practice boosted retention for the 5 facts that were practiced (the percentage of correct answers was greater than for is-

land B). However, it also worsened the memory for the 5 facts about island A that were not practiced (again compared to island B). What caused this effect?



The island A serves as the context cue for information about island A, whereas island B serves as the context cue for information about island B. When the 5 facts about island A were retrieved from memory, their connection with the context cue was strengthened and the connection of the remaining 5 facts with the context cue was weakened (see "Testing effect").

The main implication of this study for learning is that selective practice testing substantially boosts performance for the practiced items but can also worsen the performance for the unpracticed items. How can we combat forgetting caused by interference?

One way we can overcome interference is by making it explicit. If there are concepts that you get mixed up frequently then put them side by side and re-study them at the same time.

The general idea is that whatever you are studying, it is good practice to make different concepts as distinctive as possible.[25] This forces your brain to encode them as dissimilar memory traces. You can achieve this by stressing the differences between different concepts from your study material (by comparing and contrasting, for instance).

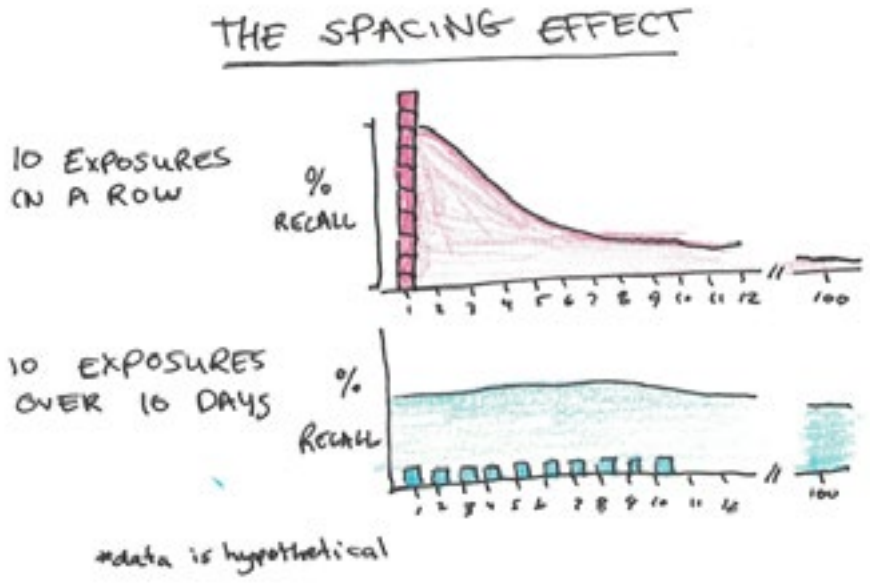
Another effective strategy is to integrate the concepts.[26] For instance, if you are memorizing the members of a particular animal/plant family, then try to find all possible relations between the members. When you're later retrieving these members, they will no longer compete for access to consciousness as they will be encoded closely together in an integrative manner. Instead of one concept blocking the other, they will be retrieved simultaneously.

Scientists have found that our study goals also impact on how well we overcome interference.[27] Students who focus on comparative performance (how well they do compared to other students) tend to use superficial processing (do not look for relations among concepts), whereas students who aim for mastery tend to use more deeper processing, such as establishing connections between different concepts.

In summary, we recommend the following:

- Re-study concepts that you confuse
  - Use comparing and contrasting to find differences between the concepts
  - Integrate the concepts (find the relations between them)
- Aim for mastery in a subject, do not pay attention to other people's performance

Spacing effect: Study less, remember more

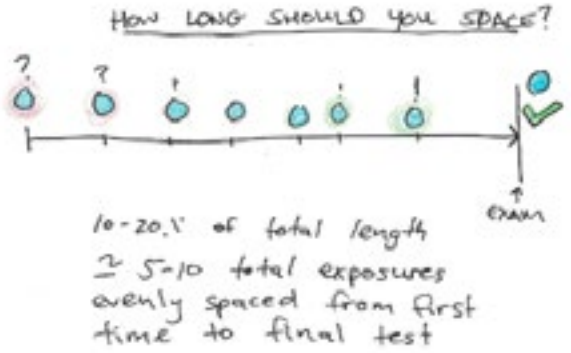


The spacing effect is undoubtedly one the most important discoveries in the science of memory. The general idea of spacing is that to achieve the same performance at a given test, you need substantially less time overall to memorize something if you spread your study into multiple sessions as opposed to if you study everything in a single session. As a demonstration, consider an experiment that the famous psychologist Hermann Ebbinghaus performed on himself:[28]

Ebbinghaus studied 2 lists of words on two following days. On the first day, he spent 1 minute studying list A and 7.5 minutes studying list B. On the second day, he had to spend another 20 minutes on list A to memorize it perfectly. However, he needed only 7.5 extra minutes to memorize list B.

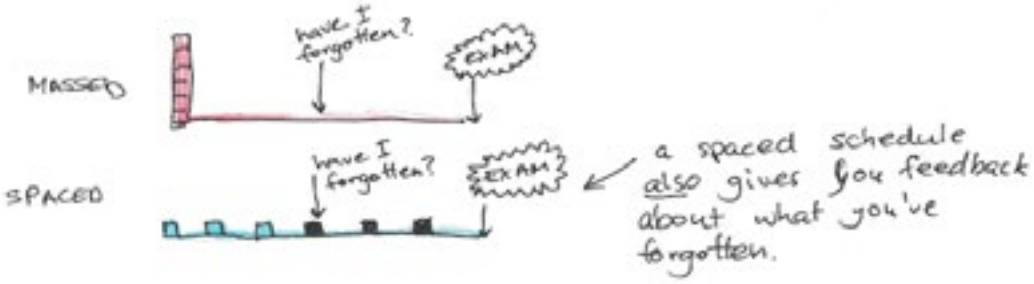
By spacing the sessions more equally for list A, Ebbinghaus managed to save himself about ¼ of total time spent on studying. In a similar way, if it takes you 3 hours in a row to prepare for a test, you may need less than 2 hours in total if you divide the time into 2 or 3 equally-sized sessions spread across several days.

In general, the more you spread your sessions, the less overall time you will need. Scientists recommend that the spacing distance should be about 10-20% of the test delay.[29] If your test is in 10 days, you will benefit most from studying once a day. If your test is in 6 months, you should study every 20 days.



Spacing not only substantially saves time, it also boosts long-term retention. Each study session that is followed by immediate or delayed sleep provides another opportunity to consolidate the studied material (we cover consolidation processes above). Furthermore, spacing can give you more opportunities to associate the study material with more states and contexts (physical, mental, environmental), which makes it easier to retrieve it in the future (see state-dependence and context-dependence).

Most importantly, spacing effectively reveals to your brain that forgetting is taking place – a crucial signal that is not available in massed practice (= if you study for many hours within a single session). The signal of forgetting has been found to automatically encourage more effective encoding strategies in students.[30]



The spacing effect is a robust phenomenon in psychology and is extremely effective for a wide range of study materials (including foreign language vocabulary, math problems, spatial information).[31]

The key idea behind spaced repetition is that revision of a particular concept should be done right before the concept is about to be forgotten in order to achieve maximum time-efficiency and length of retention. As there is no formula that could calculate this exactly, you need to experiment with yourself. For practical reasons, it is probably best to use a specialized software that uses a spacing algorithm.

Although there is currently no comparison of the effectiveness of different spaced-repetition algorithms, popular choices include Anki, Quizlet or Supermemo. We recommend that you experiment with a program that is free on most platforms, explicitly states the algorithm used and allows you to tweak it (our favorite pick is Anki).

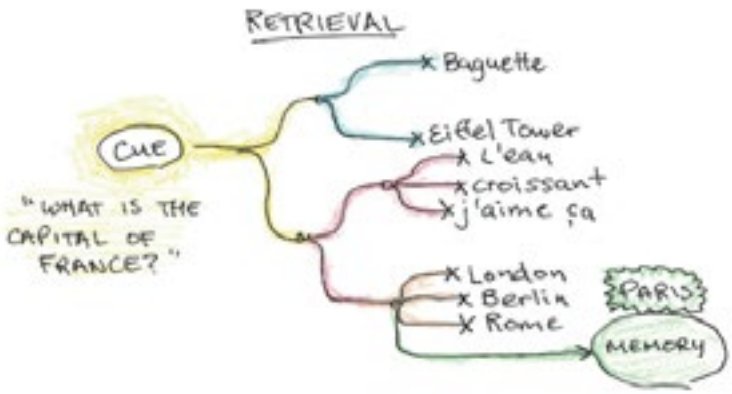
Bear in mind that the spacing effect does not continue indefinitely. For example, ten 1-minute sessions will likely not be better than one 10-minute session. This is because starting each learning sessions carries some costs with it (you have to start to focus, 'load' the material into working memory, etc.). **For this reason, complex subjects may require longer study sessions for learning to be effective.** For instance, it may be better to have three 1-hour sessions per week for your engineering class than six 30-minute sessions. It all depends on the subject studied.

In summary, we recommend the following:

- Avoid massed studying (i.e. many hours in one session)
- Divide your study sessions into smaller blocks spread out over longer periods of time
- The distance between study sessions should be about 10-20% of the test delay (e.g. for a test in 10 days, study once a day)

- Schedule your revision of each concept/topic to about the time that you would forget it (this needs self-experimentation as there is no formula to calculate this precisely)
- Consider using a flashcards program (Anki, Quizlet, Supermemo)

Retrieval: Accessing Memories in Your Brain



Retrieval is the mechanism of accessing information stored in memory. Successful retrieval of a memory trace hinges on its associations with cues. A cue is anything that is connected to the memory trace (physical object, situation, time period, word, question). Scientists believe that memories are retrieved through the process of 'spreading activation'. Once a cue is activated in the brain, the activation spreads from the cue to the target memory. A single memory trace can be connected to an infinite number of cues. If none of the relevant cues is activated, the memory trace cannot be retrieved, even though it may be well stored in memory.

As an example, try to remember the capitals of the following countries while covering the rest of the page:

- South Korea
- Syria
- Denmark
- Colombia
- Afghanistan
- Thailand
- Venezuela
- Turkey

Could you remember all of the capitals? Do you feel that you know their names and may be able to remember them later? You may be experiencing

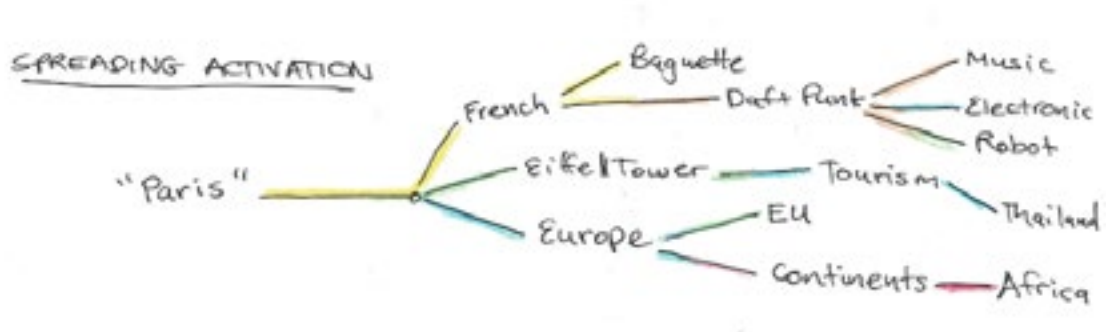
the tip-of-the-tongue phenomenon: you know that you know something but still can't remember it. Now try the same exercise with a little help:

- South Korea S
- Syria D
- Denmark C
- Colombia B
- Afghanistan K
- Thailand B
- Venezuela C
- Turkey A

Did you remember all of them now? You most likely remembered more of them. This is because the starting letter functions as a suitable cue that is connected to the capital's name. When the cue is provided, the memory trace storing the capital's name becomes automatically activated.

How does the process of retrieval function and what are its implications for learning? What can we do to maximize our chances of successfully retrieving information?

Spreading activation: Gain quick access to your memory



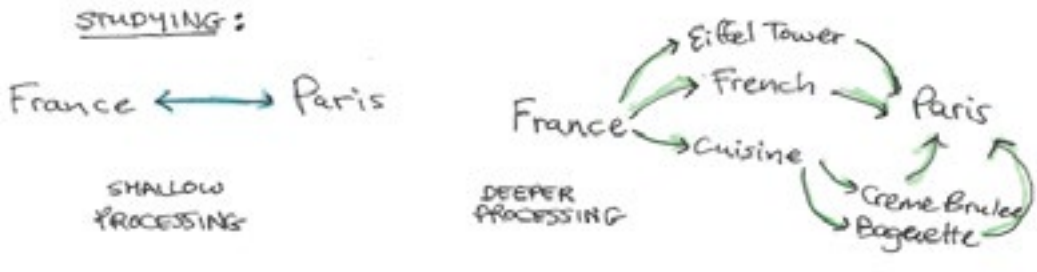
Imagine that you are preparing for a test on all capital cities in the world (given a country, you have to state the capital). If you used the most basic learning strategy, you would simply learn to match each country with its

corresponding capital. Alternatively, you could look at pictures taken from these capitals, maybe watch short videos of people speaking the country's language, visiting the capital sights and so on.

Which strategy would be more effective?

The first strategy would be called 'shallow' processing because you would not be giving the information any additional meaning. You would be making only one connection between the cues (countries) and the target memories (cities). The second strategy would be called 'deep' processing as you would be drawing many connections – between the capital, the country, its people and its sights, and so on.

If you adopted the second strategy, you would be making use of the structure of your memory. Memory is believed to operate on the principle of spreading activation.[32] If you encounter one concept (a country), the neural pathways representing this concept are activated in your brain. As a consequence, nearby neural pathways encoding closely related concepts are also activated. Images and ideas come to your mind. For instance, when someone says France, you may visualize the French flag, the Eiffel tower, French wine, cheese, etc. This process continues to further and further concepts until you start thinking about something else.



If you previously connected these images with both France and Paris, the cue France will activate additional related cues (Eiffel tower, wine, cheese, etc.) and together they will generate more activation than France alone, which spreads to the connected memory trace – Paris. Conversely, if you studied the France-Paris pairing superficially, seeing the word France

might not generate sufficient activation on its own to trigger the memory trace of Paris.

The main implication of spreading-activation is that in order to maximize the chances of remembering new concepts, **you should try to make as many connections as possible between the new concepts and what you already know.** If the target concept is connected to many other concepts, the chances of it getting activated (and retrieved) are generally much higher than if it only has few connections.

In summary, we recommend the following:

- When learning a new concept, connect it to the things that you already know
- The more connections you make between the new concept and old concepts, the more easily it will be to remember the new concept

Retrieval failure: What to do if you get stuck in an exam

Retrieval failure or the failure to remember a memory trace can have multiple reasons. One reason can be a lack of attention during study. Researchers have found that students who do a secondary task while studying underperform in a later test by as much as 30-50% compared to students who focus on one thing at a time.[33] These results suggest that multi-tasking – doing of many activities at once – is particularly harmful to learning.

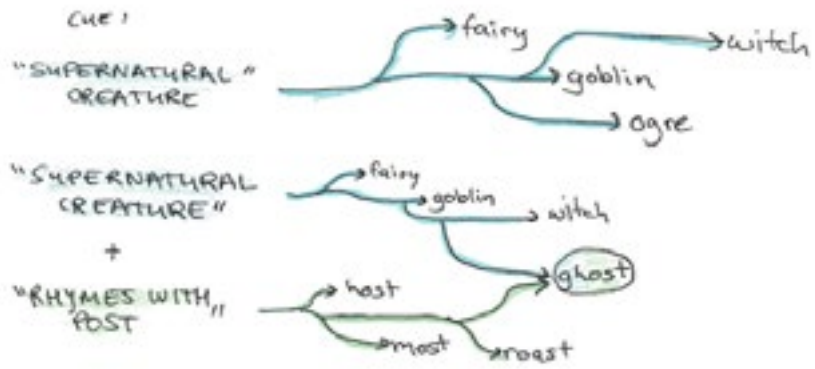
Another reason for retrieval failure is an insufficient number of activated cues. Cues are pieces of information which are connected to the target memory trace and which must be activated for the memory trace to be retrieved (for more more detailed explanation of context cues, see sections on Retrieval and Interference).

Activation from the cue to the target memory trace spreads faster if more cues are activated simultaneously. As a demonstration, try the following little experiment:

Think of the name of any kind of supernatural creature.

Now think of a supernatural creature that rhymes with 'post'.

Did you think of 'ghost' on the first time or only after the second question? The first question gave you only one cue, which led to multiple possible target memories. For instance, you may have thought of fairies, gnomes, angels and the like. The second question gave you 2 cues. These two cues jointly generated enough activation of the word 'ghost' that far surpassed the activation of other concepts. Therefore, the word 'ghost' was retrieved.

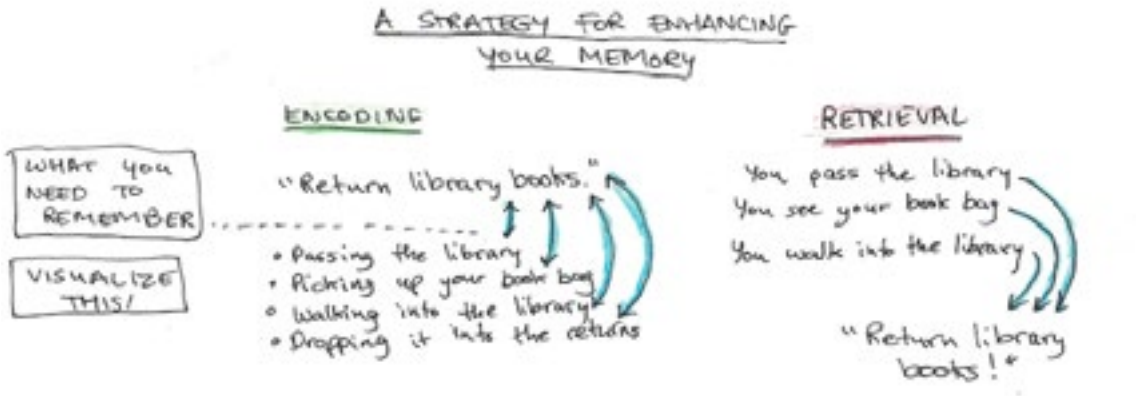


Consider another example from everyday life: You decide to return a book to the library while sitting at the kitchen table. Later, as you pass the library on your way from school, you forget to return the book. However, when you come back home and see the kitchen table, you suddenly re-

member. Memory traces are encoded together with the context present at encoding. Although the library would surely be a far more relevant context cue than a kitchen table, it was the kitchen table – not the library – that was present during encoding and thus encoded with the intention.

When you are forming an intention, it is very useful to imagine yourself doing the desired action in the desired context as vividly as possible. For instance, visualize yourself passing the library, entering the building and returning the book. Focus on the details – which objects/buildings are you likely to notice on your way round the library? By doing this, you connect the cue of passing the library (and the surrounding objects) to the intention. When you later pass the library, it will automatically trigger the intention.

If you are struggling to remember an important concept during your exam, you need to activate as many connected cues as possible. For instance, try visualizing yourself in the context of studying. Be as vivid as possible – imagine yourself with an open textbook, taking notes, sitting at your desk. Simply imagining the context of encoding can be helpful to generate enough activation to successfully retrieve the memory trace.



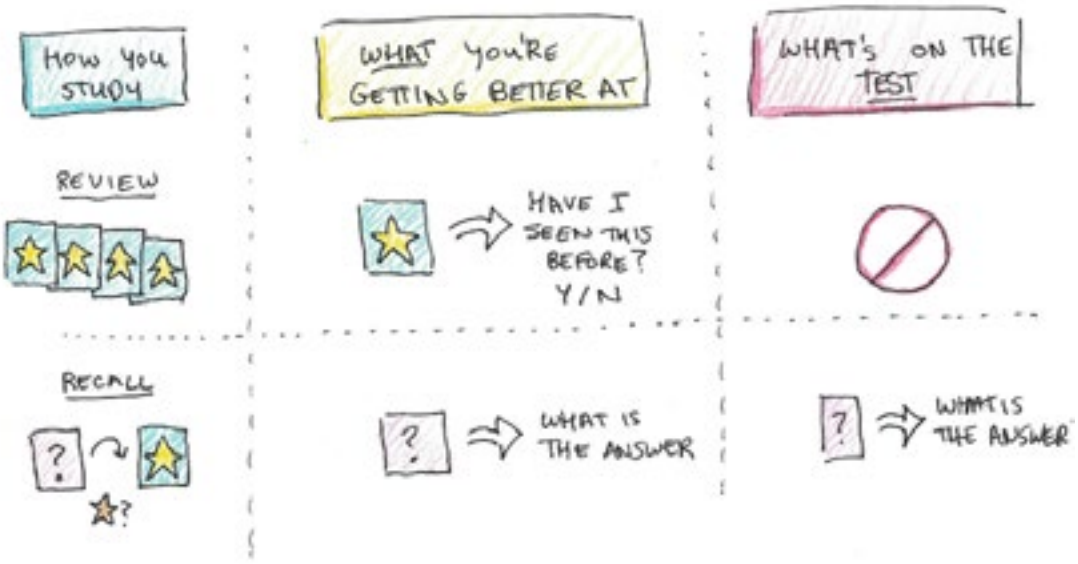
Also, try to remember the details of the context in which you studied the particular concept you are struggling with (such as what page it was in the book, what other concepts you studied before and after this concept). Note that for successful retrieval it is important to activate the connected cues.

Since our memories work like snapshots (everything that is present during encoding is encoded together with the memory trace), these cues can either be relevant (such as related concepts) or even completely irrelevant (such as the time of day or even what you had for lunch around the time of study, etc.).

In summary, we recommend the following:

- To better remember to do something in a particular place and time in the future, visualize yourself vividly doing it (e.g. imagine yourself passing the library and returning the book)
  - visualize the details of the context where you need to remember the intention (objects, buildings, people)
- If you cannot remember a particular concept that you studied during your exam:
  - Actively remember as many concepts as possible which are related to this concept
  - Actively remember as many concepts as possible which you studied before and after this concept
  - Visualize yourself in the context of studying (sitting at the desk in your room, etc.)
  - Try to remember what time and where you studied the concept, what kind of mood you were in and what had happened on that day

Practice tests: The most powerful technique for boosting memory



Scientists have found that regardless of type of test/exam you are going to take, you stand the best chance of succeeding if you revise with practice tests.[34] As a demonstration, consider the following experiment:[35]

Students attended a 20-minute Statistics lecture, which was divided into 4 equally long sessions. After each session, the first group took a practice test (without feedback), the second group had to re-study the lecture material and the third group performed mental arithmetic. All students were assessed with a final test after the lecture.

Although the re-reading group had more exposure to the material, their final test performance was substantially worse than that of the testing group (by 30%). Moreover, students who re-studied the lecture material did not perform any better than students who did a completely unrelated arithmetic task.

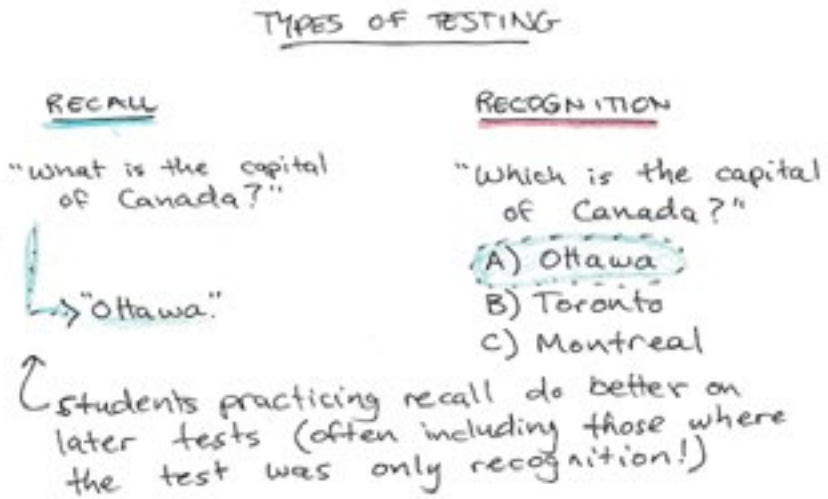
A wealth of research has shown that testing is more effective at improving retention and test performance than re-studying, even if no feedback is provided. This is called the 'testing effect'. However, not all tests are created equal. You will greatly benefit from practice testing only if you revise with tests using a particular retrieval mode – recall.

Recall is a way of retrieving a memory trace when you do not see the correct answer and do not have any options to choose from. Example recall questions could be: "What is the population of Canada?", or "What is the German word for Monday?"

The opposite of recall is recognition, which is a way of retrieving a memory trace when you see the correct answer or a set of options that includes the correct answer. Example recognition questions could be: "Is the capital of Canada Ottawa or Montréal?", or "Is the German word for Monday Dienstag or Montag?".

Regardless of how your knowledge is tested in the end, recall testing is vastly superior to all other learning methods based on recognition. One of the reasons for this is that it automatically encourages deeper processing of the study material. In the study above, the testing group took increasingly elaborate notes as the sessions progressed compared to the other groups (without being consciously aware of it).

The most important reason is that recognition is easy for the brain because it knows exactly which concept it must retrieve from memory. If you reread your notes, you are in fact asking your brain: do I know this? Does it sound familiar? If you have already studied the notes at least once before, you are in effect telling your brain: "I've seen this before, there is no need to make any further effort".



In contrast, recall is effortful because the brain has to figure out which target memory is to be retrieved. If you test yourself with recall (questions with no hints or answers to choose from), your brain has to reconstruct the pathway from the question to the target concept. In this manner, the pathway is strengthened (or new pathways are built) and as a result, the concept becomes more easily retrievable later.

Note that the recall has to be successful – unsuccessful recall does not strengthen the memory trace. The best time to revise concepts is therefore just before they are about to be forgotten (see our section on spacing effect).

Virtually all methods commonly used in studying engage primarily recognition processes, such as reviewing (re-reading), highlighting or open-book summarizing. It comes as no surprise then that these learning methods have been shown to have little to no utility in improving retrieval success and test performance. Other methods using deeper processing such as self-explanation are far more useful than re-studying but still not as effective as practice testing.[36]

However, it is not the case that re-reading has no value whatsoever. Re-reading is useful inasmuch as it is used together with practice testing. It is definitely a good idea to selectively re-study the concepts which you cannot recall.

Also, it is important to re-study material during practice testing as a form of feedback. Although practice testing without feedback is very effective on its own at improving memory, if errors go uncorrected, they build up over time and become more and more firmly lodged in memory. For this reason, feedback is an essential complement to practice testing that substantially enhances its effectiveness. It does not matter whether feedback is immediate (straight after each question/problem) or delayed (after the study session).[37]

Finally, do not forget that practical usage your knowledge (such as doing a

real-world project) also amounts to a form of practice testing (and spaced repetition) where you have to regularly retrieve your knowledge and skills from memory. A fair amount of real-world practice can be superior to extensive theoretical study.

In summary, we recommend the following:

- Avoid learning strategies based on recognition (reviewing/re-reading of textbook chapters/notes, highlighting, summarizing)
- Revise with practice tests / questions to achieve the best results in your tests and exams
  - Use free recall (questions/tasks with no hints or options to choose from)
  - Practice with recognition questions (such as multiple-choice) only if your test will also be multiple-choice (see transfer-appropriate processing) and for 1/4 of your study time only
  - Selectively re-read only the material that you cannot remember
  - Get immediate or delayed feedback on your answers Revise with practice tests / questions to achieve the best results in your tests and exams

Summary of Key Methods for Enhancing Memory

Let's recap what we've learned!

Memory has three parts: encoding, storage and retrieval. All three need to function successfully to remember what you need to.

To encode information better:

- **Process information deeply.** Pay attention to the deeper meaning, make connections to what you already know and paraphrase rather than take notes verbatim.
- **Intention doesn't matter so much.** Trying to remember more doesn't make a difference if you use the same cognitive strategies!
- **Match your practice and studying time to how you'll eventually use the information.** Greater overlap means you'll remember more later.
- **If possible, align your state and context when you're encoding the information to when you need to remember it.** If this isn't possible, study in more environments/situations to make your memories more robust!

To store information better, you need to be aware of how you forget. Here are the main possible causes of forgetting:

- **Trace decay.** This occurs when memories get old, or new knowledge overwrites the old data. Refresh important information on a schedule so it doesn't get lost!
- **Interference.** This happens when a new memory blocks an old one (e.g. you can't remember the Spanish word for water anymore because you learned the French one.) Alternatively, it can happen when old memories make learning something new harder.

How can you store your memories better?

- **Get enough sleep!** Short naps can recover energy. Longer naps (60+ minutes) can enter the phase of sleep where memory consolidation happens. Ending your naps on a full sleep cycle can prevent grogginess. Of course, getting enough sleep at night is essential!

- **Space out your practice.** Done properly, you can get the same memory strength with 20-30% less time by spacing properly.

Finally, you need to retrieve the memories in the situations that need them. How can you do this?

- **More connections help.** Memories are likely accessed by spreading activation, so if you think of related items, that can help you retrieve something difficult.
- **Plan ahead and visualize the context** you'll need to retrieve something in when you study.
- **Practice testing is the single most-effective technique you can use!** Practice recall, not just recognition. Harder recall creates stronger memories.

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