An Overview of Learning and Memory as Applied to Learning and Teaching

I think that understanding the mechanisms of learning ought to help us learn and teach better. Astonishing advances over the past ten to twenty years are, I believe, only beginning to give us better ways to learn and teach. In this overview, some recent findings (and some not-so-recent findings) are used to derive some conclusions about learning.

We'll start with recent findings and some conclusions about learning and memory.

1. Brain areas of learning and memory

We use different major areas of our brain for memory: visual cortex, auditory cortex, somatosensory cortex, motor cortex, and other regions. Memories are created using different brain areas for different kinds of memories: the hippocampal pathway for the kind of memory we can pass to others in words (declarative memory), the neostriatal pathway for skill memory (also called motor memory, muscle memory, or kinesthetic memory), or amygdala pathway for emotional memory (such as fear memory). Memories of each specific type are created using just one of these pathways.

For learning, we need both to create a memory and to recall it. Once we have a memory, remodeling or removing a memory can make it weaker and eventually even impossible to recall. Using more brain pathways to create a memory gives us more hooks to recall that memory. Furthermore, the more brain areas involved in that memory, the more interesting the memory is to both create and recall. If we use only visual cortex to develop a memory through reading, then we have only that one way to recall it. While creating that memory with only one brain area, say by reading and rereading, we'll be more likely to be distracted or bored, making it harder to form the memory. If we combine visual cortex (view it repeatedly), somatosensory/motor cortex (sketch it or write it repeatedly), and auditory cortex (say it repeatedly), the memory holds our attention better while being created and is more easily recalled later.

Recall that motor memories, using movement, follow a completely separate and independent brain pathway to lay down and recall. Thus, motor memory provides a completely different but connected way to learn and retain information. We can create motor memory by sketching, hand movements, dancing, or any other kind of movement. Because sketching can provide both a visual memory and a motor memory, and because sketching is easy to do on paper during an exam (or by drawing in the air with your hands), repeated sketching of something we want to memorize can help create memories that are easily recalled.

Conclusion: the more brain areas used to create a memory, the better our recall.

2. Learning needs to be matched to task.

In the courses I teach, exams require problem solving, either in multiple choice questions or essay questions. My exams almost never involve matching a word with its definition, or matching an example you saw in the book or in class with a term or definition. In class, students are provided with the necessary terms, definitions, principles, and examples. We use all of those in class to solve the kinds of problems I give on exams, and I also post old exams with many more problems.

Some of my students choose to memorize the terms and principles (sometimes even perfectly), understand them well, and yet do poorly on exams. How can that be? It turns out that they're studying for one kind of exam (memorization/matching), and I'm giving them a different kind of exam (problem solving). So how does that matter? Well, imagine that I tell you, "Next week I'm going to give you a test on tennis". If you've never played tennis before, you might read about the rules, techniques, and everything else you can find about tennis. You memorize it all perfectly, and you practice until you can recite it perfectly. Exam day comes. I hand you a tennis racket and say, "your exam is to play a match". How will you do?

Conclusion: fail to match learning to the task, and you'll fail the task

3. Understanding and information reduction

When you read your text or hear a lecture for the first time, you need the full set of words and images. Without a complete set of words and images, you can't be sure that you understand exactly what is being explained, and you have no way to check to be certain you understand it fully. Once you understand something fully, though, you might never need to see or hear that full set of information again. All you need are the key elements that will help remind you of the full concept. You need what are called 'chunks', condensed versions that remind you of the entire concept.

Experts learn and think by creating and using 'chunks' in memory. A chunk is some concept, structure, or series of events that can be held as one item in working memory. Working memory can be defined as the amount you can hold in your mind all at once—which might be seven numbers, seven words, or seven related events. Why seven? Seven items is the number most people can hold in working memory. Experts are fast and complex thinkers not because they hold more things in working memory, but because they have automatic recall of more chunks and can connect those chunks in more complex ways. In order to create and hold a chunk, an expert is good at creating the simplest possible version of a fact or idea that still holds all the key elements.

You are doing the initial steps of chunking each time you describe a movie or a book to someone else in just a few minutes. You do that by pulling out the key themes, concepts, actors, and events, and recalling them in a highly simplified form. However, done well, that simplified form may allow you to recall everything important in the book or movie. As you review the simplified chunk in memory, important details come back.

Despite what we know about chunking, it is still rare for teachers and professors+ to get or give instructions on <u>how</u> <u>to</u> <u>chunk</u> while learning. As learners, we're given the full story in a lot of text and illustrations, and left to figure out the chunks on our own. That makes learning MUCH harder. (The 'minute sketch' tool is designed to show you how to chunk.)

Imagine that I want you to understand something. Let's say I want you to know that events A, B, and C, using structures X, Y, and Z, are involved in the biological mechanism of muscle contraction. In my classes, it might take me two hours to explain all of this the first time. However, once my students have listened and understood that A, B, and C using structures X, Y, and Z are involved in muscle contraction, I can review it completely in just a few minutes. All of it, with nothing important left out! With practice at this, if my students have A, B, and C with X, Y, and Z in front of them in a sketch, they can make very complicated predictions about the effects of a disease or a drug on muscle contraction. An astonishing thing has happened! What took two hours to hear and understand is now condensed into just a few minutes. When my students do this, they are using chunks.

Conclusion: information reduction and chunking is important for expert thought.

4. Problem solving requires fluent or automatic recall of chunks.

A novice begins with no understanding and no recall of a topic. As novices begin to learn, they attain understanding each new topic. Of course, understanding is just a first step. It is entirely possible to understand something but have no recall of it. On an exam, or in real life, a novice might be able to use knowledge that is understood, but not recalled, but only if someone or something gives them the information. They have to have a way to find what they cannot recall. Without recall, the need to find missing pieces makes problem solving very slow. For most of the knowledge that makes someone an expert, we're not willing to accept understanding withut recall. Instead, we require that experts have automatic recall of fundamentals to solve problems. As they are learning, novices need to be able to recall much of what they understand in order to work through a problem. (Ask yourself this: how much would you trust a professor, a doctor, lawyer, electrician, or plumber who keeps saying, "Well, I know I understood this at one time, but I'll have to look that up.") We expect any expert to recall all of the basics, and need to look up only things that are unusual or perhaps especially complicated.

There are different levels of recall. Recall can range from effortful to automatic. Effortful recall is remembering something, but needing to work with full concentration in order to achieve recall. Effortful recall allows only the simplest problem solving, if even that much. Effortful recall will allow someone to answer simple memory recognition questions. However, effortful recall won't let someone solve any but the simplest problems. The effort of recalling the topic takes most of the attention and concentration of working memory, with little or nothing left over to hold a problem or solution.

Fluent recall is recall that comes quickly, without effort, but still requires the attempt. In fluent recall, a person decides to recall X, and there it is in memory. We all achieve fluent recall, for example, in middle stages of practicing multiplication tables. We have fluent recall when we see 7 x 8, and think to ourselves, in words in our mind, "seven times eight is fifty-six". Fluent recall works fairly well for problem solving, but not perfectly. Having to think "seven times eight is fifty-six" takes part of working memory, which limits the complexity of problem solving.

Automatic recall happens without conscious attention. The problem might call for X, and X is immediately available. Automatic recall occurs when you think, "Mom could tell me this, "and your mother's phone number pops into your working memory. Automatic recall occurs when we've practiced so much that as soon as X is relevant, X is present in working memory. Automatic recall develops, for example, at the late stages of practicing multiplication tables when a person sees 7 x 8 and immediately "56" pops into their working memory. There was no need for the step of thinking "seven times eight is fifty-six". Automatic recall is most effective for complex problem solving. (By the way, I'm not convinced that everyone practices their multiplication tables long enough to achieve automatic memory, which I suspect gets in the way of solving many math problems later in high school and college.)

How do you achieve automatic recall? Practice, practice, practice. You can either think about X in many different contexts and ways, so often that it sticks, and/or you can get X into long-enduring motor memory by repeated speaking, sketching (or moving your hands or dancing or ….). Experts use multiple ways to develop automatic recall. In my field of research, whenever I need to achieve automatic recall for some new idea, by far the fastest way to get there is by creating a chunk and sketching that chunk over and over, with the words along side (using the 'folded list' tool).

Conclusion: Automatic recall needs practice, practice, practice.

5. Staying interested in new learning

People enjoy learning, BUT three conditions are necessary. First, the topic has to be non-obvious—at least a little new and challenging. If X isn't new, then why bother paying attention; if X isn't challenging, then X is too obvious to spend the effort to learn. Second, a person needs to find the topic important and relevant to them in some way. If not, no matter how much one might wish to learn, the brain will filter the topic into the 'not important, don't place in memory' category. No matter how often they review X, X will slip away. Third, X can't be too difficult. If understanding takes more time and mental effort than a person is used to applying, then they'll give up. (Of course, the more motivated a person is, the harder they'll try—if someone's life or if a million dollars is riding on learning X, they'll try a lot harder and longer.)

We can train our minds to be more interested and to accept greater challenges. How? First, we can train interest. We can practice finding connections and relevance for ourselves. We can imagine times and places in which we might use the information we're learning. Experts are good at discovering meaning in new knowledge (but not necessarily on anything except their field!). Second, we can train ourselves to believe that we can learn and understand and apply new knowledge. When we practice and gain experience trying hard, overcoming failures, and getting up to try again at something very difficult can make someone a much better learner, as long as they DO eventually learn at the end, and as long as they believe it was worth the effort.

Please don't mistake me here. It won't work for a well-meaning relative or friend to just try to build your confidence or self esteem by saying, "You can do it"! What you actually need is justified belief in yourself. You can get justified belief in your ability in two ways. One is by having faced hard problems in the same topic area in the past, and found that with hard work you mastered those problems. The other is by have a person who you can trust has the experience to predict accurately that you can do it, and no reason to give you artificial hope. Parents, friends, and even teachers are sometimes unhelpful at this. They care too much about you, and that's a problem in this case. If you know that a person often tells you something just to make you feel good—just to build your self-esteem—then you can't trust that they really KNOW you can do it. It's nice to know they care about you, but that won't necessarily predict your success at learning X. Unjustified confidence is a fragile and dangerous thing. Earned confidence, on the other hand, is immensely valuable; whether you are giving support or receiving it, learn to tell the difference!

Conclusion: Make it interesting, challenging, and achievable, and learning will happen.

6. Study time

There are many poor ways to study. Worst is any form of study that makes you bored. You might still learn something, but the odds are that you will learn it poorly and very slowly. That creates a problem. Once we understand something, our minds are bored by having to go through every bit of it all over again. Why is that a problem? Because books and lectures are created for that first reading or hearing necessary for understanding. Once you understand a part of a concept (or all of a concept), using the book or lecture or your notes to start creating fluent or automatic recall is dull.

Think about this, and it should make sense. Think about a book or movie that you REALLY enjoy, and that affects you deeply. Do you IMMEDIATELY sit down and see it or read it again? Alternatively, do you appreciate it by recalling the key pieces and thinking about them? Except for the rare favorite book or movie, rereading or rewatching right away can be excruciatingly boring, even for something we found really interesting on first viewing. And yet, when studying, people try to learn by reading and re-reading their textbooks and their notes over and over again. DULL DULL DULL !

Just as when you learn a concept for the first time, study time is best when studying is interesting and challenging, but not too challenging. One can make study time interesting and challenging, but it needs a method. The key is to use study methods that engage more brain areas, doing more things, ALL of which help you develop automatic recall and deeper understanding. How can you do that? Use your mind to solve interesting problems of information-reduction to create useful chunks. Use more of your brain regions by moving and sketching (and saying) those chunks to use motor memory while you learn. Any writing or sketching MUST be in chunks, otherwise it takes too long and is too dull. For example, many of my students recopy their notes. I think recopying notes is better than just rereading, but I think there is a better and faster way to stay interested: creating chunks and practicing for fluent recall and thinking with those chunks. (Again, 'minute sketches' and 'folded lists' are designed to do this.)

Conclusion: trying to memorize **everything** by repeated review of ALL material is boring and unnecessarily complicated; information reduction to key elements (chunking) and practice problem solving is more interesting, challenging, and effective.

7. Problem solving

In the sciences (and history, and …) everything we teach and try to understand has some physical reality. It's easier for most of us to learn and use material if part of our chunking and fluent recall includes simplified images that capture a concept, not just words.

I think I can demonstrate this best with an exercise I do for many students when I am teaching them chunking and problem solving techniques. Imagine that I give a student a set of definitions: territoriality, energy cost, risk cost, opportunity cost. Imagine that they memorize

Territory: an area defended against other individuals of the same species

Cost: Resources (such as energy or nutrients), additional risk, or time needed each time a behavior is expressed.

Resource cost: energy and nutrients that could have gone into reproduction

Risk cost: increased chance of being injured in a fight or eaten due to lack of attention to predators.

Opportunity cost: loss of time for feeding or other behavior.

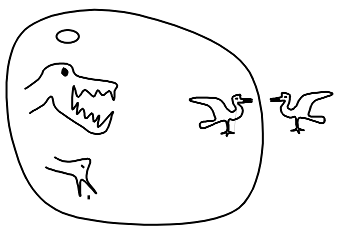
and understand them all.

Then I give them a problem to solve: what should happen to territory size if risk cost is reduced? Here's the process they must go through to solve this problem:

Identify task → recall words of the definition → convert to some kind of physical representation in imagination to predict outcome → convert back to words and answer

When I do this exercise with students in my office, usually the student either cannot get the right answer this way, or if they do get it, they're not at all sure of their answer. Even when they're right, I can hear uncertainty quite clearly in their voice.

Now imagine that we redo this process, but now I provide the same concepts with the definitions above **<u>and</u>** a minute sketch to chunks the concepts.



Territory defense behavior

Resource cost (egg)

Risk cost (predator)

Opportunity cost (lost food)

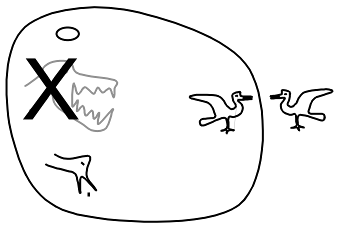
In this minute sketch, the territory is represented by the line, and defense of the territory by the bird facing off against an intruder of the same species. Resource cost is represented by the egg→ energy and resources that go into defense cannot be used to make eggs. Risk cost is represented by the toothed head→ while distracted by territory defense, the bird is more likely to be eaten. Opportunity cost is represented by the feeding head → if the bird is defending the territory, it cannot also take the opportunity to feed. Notice that I could have used other things, because resources can go into additional fat or muscle, risks can be risks of injury or disease, and opportunities lost can be for grooming to remove parasites or searching for mates. However, the central idea of each of these costs, the concept of territory defense, and the territory itself is nicely captured in this chunked sketch. The text is off to one side, in approximately the same order and location. The terms are important, but it is visually very distracting to put them on the sketch. (*Why? Because your visual attention can either comprehend an image or read, but NOT both at once. Put them on the same sketch, and your working memory is distracted by wanting to go back and forth. Try redrawing this sketch with the labels, and see if it is easier or harder to think through.*)

Now, with this minute sketch, I ask the student to recopy the terms & sketches in a 'folded list', back and forth, two times (this takes about three minutes). Then I cover the paper. I ask my student to close their eyes and explain the concept to me. As I watch, most (not all) of them use their hands to draw out their sketch in the air. It appears that they are now using motor/kinesthetic memory to help recall the sketch and the concept.

Finally, I give them the same problem (or a different one). What should happen to territory size if Risk cost is reduced? (Alternatively, I can ask them to predict what happens if the animal is starving, or if energy cost decreases, or …). Now, the process to solve the problem has changed! Now they:

- *Identify task → refer to and manipulate the sketch in the form of a physical representation in imagination (or quickly drawn on paper) and predict the outcome → describe what they see as the answer.*

They find this MUCH easier, and they are faster. Before, they had to take a completely different practiced task (memorized words), and in order to attempt an unpracticed task (conversion of words to a representation of physical reality, solve problem, and then convert back to words). With the chunked sketch, they have a practiced task (image of physical reality) that they can manipulated in their head or on paper in order to predict and explain the outcome. Below is a modified version of the sketch to show that risk cost is reduced (or gone).



Territory defense behavior

Resource cost (egg)

Risk cost (predator)

Opportunity cost (lost food)

Now, students say something like the following: "If there are fewer predators, then there will be lower risks for territory defense. Therefore, since territory defense will be cheaper, there can be more time spent defending the territory, and so territory size should increase." Consistently, students get the right answer. Even better, they KNOW it's the right answer without me confirming it, and I can hear their certainty about being correct in the tone of their voice.

When I do an exercise like this in my office with a student, I time how long it takes to think through the definitions *versus* redrawing the sketch and terms while thinking through each term. Nine times out of ten, students are faster drawing the sketch and listing the terms than they are at reading the terms with the definitions. They also learn the concept faster, and develop better recall for the same amount of effort.

Conclusion: Learning methods that represent concepts and facts as something akin to what they are, using simple sketches and images, are easier to use in problem solving.

****

So how can you teach yourself (or someone else) how to use these ideas? There are many possible ways.

With my students, I use __**Five**__ major tools (all can be found on my learning website):

(1) Minute Sketches: physical representation as chunks in a simple sketch engaging motor memory

(2) Folded list: matching and practice transferring and connecting between different functions—words and abstract meaning with minute sketch representations of reality

(A) Connections between auditory/sequential functions of brain and visual/spatial functions of brain

(B) Creates and connects chunks for the concept with chunks for the terms

(C) Provides a method for information reduction, and chances to test to see whether information reduction went too far (too much detail) or not far enough (still don't understand concept)

(An entire lecture should be reducible to 1/3 of a page on a folded list)

(D) Also engages multiple brain areas (recopying sketches and words)

(E) Also tests knowledge and fluent recall

- Memory of concept: can I recall the words and the sketch, one from the other?
- Understanding of concept: if I can't represent a scientific fact or concept in a sketch, then I don't truly understand it, and I need to go back & review.

- I think that folded lists with minute sketches are the most important learning tools I have for students

(3) Modified concept mapping: linking and connecting related facts and principles in the form of sketches, and in the process turning unconnected chunks into a logical and organized body of understanding

(4) Student practice sessions to use 1, 2, and 3 above to invent their own exam questions, matching the question style of any specific professor

(5) Test post-analysis: a method to determine by yourself what was and was not effective in your study methods, and how best to adjust your effort.

****

What might convince anyone to try these, to work at them, and to persist past the expected initial failures and frustrations at making them work?

This is not easy. Most students won't try to change. I have shown thousands of students minute sketches, folded lists, and some of the other learning tool. Perhaps one in ten tries to use them at least a little. Of the hundreds who have tried, many have given me feedback. Quite a few of these students told me that the methods didn't seem to help, and they gave up on them quickly. So what about those who stuck with it?

The majority reported that they needed at least 40 hours of practice. Usually they had to spend at least a few hours each week or so, continuing over a few months or more, to master the skills of minute sketching and folded lists. Most of them tell me that it didn't work at first, and only with more practice and multiple attempts could they gradually learn them correctly. Clearly, it requires practice and time.

Why does it take so long? These are not facts you memorize. These methods are skills you learn to apply, just like every other learning method. You may not realize it, but whatever methods you use to study right now is something you learned and practice. I suspect that it takes a complex form of skill memory to learn any learning method. Picking up a new learning methods is, I think, like learning a sport, or dance, or a musical instrument. It takes time in thoughtful and careful practice.

If a coach tells an athlete to try a new serve/pitch/pass/kick/stroke/move, a wise athlete doesn't expect to be able to make the change instantly and have the new method work every time. In fact, often the first result is that the athlete is WORSE—they've messed up their old method, and they haven't yet mastered the new method. (I remember this multiple times from developing my own skills in soccer, tennis, swimming, and other sports—my 'improved-form' tennis serve was less reliable for months before I finally nailed it.) With practice, though, and confidence that their coach is correct that the new method will become more effective, their game improves. Over time, a player gradually learns to use the new method correctly and adapt the method to their own playing style, movements, and strength. Good athletes don't expect great improvement without weeks or months of interested hard practice. Likewise, these methods rarely work over a span of a few weeks.

To improve learning, I think you have to try these new methods, try them again in a slightly different way, sometimes get feedback, keep trying and practicing, and eventually get it right. Only a few of my students have reported really good success in less than three months. Many students have reported back to me about initial low success, but that they later found, sometimes to their surprise, that over a period of a year or so these methods gradually took over their studying for almost every class.

Those students who kept trying through those many hours of practice have told me, (1) when they can't create a good minute sketch, then they don't yet understand the concept well enough, (2) they learned how to tell when they knew enough and could quit studying something, because they could tell when they had fluent recall and understanding, (3) they remembered things much longer than they expected, sometimes many months or years later, just by starting to redraw a minute sketch, (4) they could test their own understanding very easily, just by changing something in a minute sketch and trying to predict the results, (5) they could predict likely exam questions, and practice answers in advance, (6) they gradually converted more and more of their studying to use minute sketches and/or folded lists, and (7) they had either steady improvement in grades or reduced study time for the same grades.

Might this work for <u>any</u> student? Will minute sketches and folded lists work for you? I wish I could tell you. I wish I knew if they will work for you, but I <u>don't</u> <u>know</u>. Minute sketches and folded lists have not yet been tested in carefully controlled studies in a way that tells me the answer. I'm working on that. For now, though, I can only repeat what I said above: many students have told me that these methods were extremely helpful for them.

Below are two testimonials (two of many from students). These two will give you a sense of student outcomes. The first one was a rare quick improvement (and I don't actually know if AC stuck with it and had any sustained change). The second experience from JH is very typical.

1. From "AC"

"Prof. H.

My name is ______, and I am in your freshman biology class. I did not know what to expect from the course in the beginning of the year, having only taken one Biology class in high school during my 9th grade year. So I really had no good sense of what I should study, and more importantly how to study for the tests.

My first two tests were not very good. Actually, they were horrible. Especially the first one. I just felt like I had no idea how to study. I was a little overwhelmed by the material in the book, and did not know what to take from it. But during every test I improved, because I tried experimenting with new study techniques. After you sent the e-mail regarding the folded list technique, I still did not look at it very seriously. But I did give it a try, and after a few failed attempts I managed to get it right. And who would've thought. It worked. It was like magic.

On this test [test 4], I got a 94% [which was the highest score in the class of over 300 students], and I can clearly say that I owe it to the folded lists. I discovered that by reading the book, and then taking the important parts out of that, and making folded lists, studying Biology is not rocket science. In your e-mail you said that you hope the technique helps at least one person. I'm happy to say it helped me.

[Thanks ....] AC "

2. From JH

"Dr. Heideman,

So basically for me, the folded list technique has become a major tool that I use to study for pretty much every test, bio or otherwise. When you told our freshmen Bio 204 class about it, I just shrugged it off. I was getting a B in the class, and was pretty complacent about my grade. I thought, why try something new when what I was doing was working, though not as well as I had hoped. So I just read the book even more, and I read my notes from class even more. For most of my classes, I was still stuck in the B range. I was unable to make the bigger picture connections that are vitally important to understanding bio.

Then when I met with you, spring of sophomore year, and you convinced me to try it, I listened. Initially, making the folded lists was rather confusing. I didn't really know what to put on which side, which fact to cover up and so on. But once I got the hang of it (it took about 1-2 tests for me, but for some friends who use these it took longer) my grades improved drastically.

I now make A's in most of my classes. Memorizing a large amount of material isn't so challenging. But most of all, by using the folded list, I'm spending the same amount of time studying as before, but I understand and remember the material much better. By using the folded list I am able to study, get involved on campus, and find time to go out with my friends, without adversely affecting my grades or my sanity. Thanks for continuously pushing me to use folded lists, even when I initially didn't want to.

JH"