I’m going to talk about:

- What we know about the biology and psychology of learning.
- What is unique about academic learning.
- What learning strategies have been found most effective and why.

My goals are for you to be able to:

- Assess your own learning strategies with a better understanding of why they work or don’t work.
- Expand your repertoire with strategies proven to get the best return on effort.

Learning is a complex function. It’s intertwined with thinking and feeling in the most complex organ in our body, the brain, and a key element behind our behavior. For these reasons, learning research is vast, but scattered across many fields of study.

Much is known about learning, but few (if any) of us have full, comprehensive knowledge. My own expertise is in two slivers of the education field – adult education and instructional design. Over the past decade, I have also been trying to read and understand biological and psychological research on learning, with a few forays into cognitive science and artificial intelligence. It is from this narrow, but gradually broadening perspective that I speak.
Learning is inherent in the way our brains and nervous systems are structured.

The ability to learn enhances the ability to survive and reproduce, and it is found throughout the animal kingdom. Animals can change their patterns of behavior to take advantage of good food sources, find and remember shelters, and avoid dangers. In addition, humans can learn to communicate with language and work cooperatively, discover and use tools of all kinds, and pass this knowledge on to our descendants via education and culture.

**Neurons**
Neurons are the specialized cells with which our nervous systems are built. Sensory neurons react to environmental stimuli and begin processing the information in the sense organs. Sensory neurons send signals to the neurons in the brain, where information is further processed and decisions are made. Signals are sent from the brain to motor neurons that activate muscles that carry out actions in response. The nervous system is a vast army of privates, the neurons. There are no officers in this army. Decisions are made by committee. This is oversimplified, but it is essentially correct.

**Brain: mesh of connections**
Our brain tissues contain meshes of about 100 billion interconnected neurons that can signal each other electrochemically. The projections of each neuron (axons and dendrites) connect to as many as 1000 other neurons. They meet at small gaps called synapses, across which the firing neuron sends neurotransmitter that can be detected by the neighboring neuron.
Computational units
Neurons in the brain act like computational units, summing the inputs from neighboring neurons and either firing or not firing as a result. A neuron fires depending on how many and how frequently its connecting neighboring neurons fire, the strengths of the connections, whether the neighboring firings have excitatory or inhibiting effects, the kinds of neurotransmitters released, and the effects of hormones and other modulatory chemicals. So there are many variables that determine whether or not a neuron fires.

Different sensations will evoke different firing patterns in neurons in our brains. Different constellations of firing neurons are believed to represent the different things we experience in our environment as memories. Here is a group of neurons firing in a mouse’s brain, for example. We don’t know yet exactly how information is represented, and how those representations are manipulated during thinking.

A firing pattern can trigger related patterns to fire if there are enough connected neurons. When I sense something sweet, fruity, yellow, soft, and finger-shaped, the corresponding sensory constellations firing will trigger the firing of the banana constellation. The banana firing may trigger related fruits, which may trigger other foods. Banana may also trigger related constellations, like monkeys and South America. The building of these pattern relationships is part of what we call meaningful learning.
When a pattern refires, either because of repeated sensory experiences, or because of thinking or emotional processes, the connections between the neurons in this constellation strengthen. This occurs through short-term physiological changes, and, if repeated often enough, it leads to long-term anatomical changes. Here you can see that more connections have developed between the yellow neuron and the red neuron after repeated paired firings. The more often the constellation fires, the more stable and strong the pattern becomes.

When a pattern does not fire frequently enough, the connections weaken.

With the complexity of so many neurons, so many interconnections and feedback loops, and so many interaction variables, the brain is capable of generating a practically infinite variety of firing patterns. Our capacity for storing memories is practically limitless.
Much of our thinking, emoting, learning, and memory is unconscious (or implicit), automatic, fast, and effortless.

Here’s an example of how we think implicitly. You probably read the first cell as A,B,C and the second as 12, 13, 14. But notice that the middle figure in both cells is identical. We unconsciously use contextual cues and jump to conclusions. Implicit thinking gets us through much of the day, usually successfully.

Much of the learning that we accomplish over our lifetime (language, walking and movement skills, social skills) is implicit. Most of our learning of these things is unconscious and effortless.

Our memory for skills, procedures, and habits is also implicit. We don’t recall these consciously when we use them. In fact, if we try to consciously think about skills like walking, it often makes us clumsy.

If learning is so natural, then why does academic learning require such effort?

The two characteristics that I see are:

- It’s explicit (effortful)
- It’s usually artificial experience
Explicit learning of factual information involves:
- Paying attention to sensory information, which moves it into working memory in your frontal lobe.
- Elaborating on (thinking about) the information in working memory.
- Encoding the information into long-term memory through the hippocampus.
- Retrieving the information to working memory when you need to remember it.
- Consolidating (making stronger) the memory over time in long-term storage in the cerebral cortex.

Conscious thinking and learning are effortful and tiring because our attention and working memory capacities are limited. Attention is easily distracted. We can only keep about 3 or 4 items at a time in working memory, and we must rehearse them to keep them there. To demonstrate this, try multiplying these two numbers in your head without using paper pencil, cell, phones, laptops, etc.

Did you get 306?

It’s difficult, because you have to keep the sub-products and carry numbers in your working memory all at the same time while performing other operations. It exceeds most people’s working memory capacity.
Given the constraints of attention and working memory, how do experts have such good command of knowledge in their field (as you hope to do)?

Several decades of research have identified some clear differences between experts and novices at a variety of tasks. Expertise have more knowledge, it’s more meaningfully organized in their minds, and it’s better cross-linked.

- Because their knowledge is organized, they can think in categories, which gets them around the 4-item bottleneck in working memory.

- Because it’s organized by meaning rather than by surface features, then can retrieve it more easily in applicable situations.

- Because it’s cross-linked, they can more easily retrieve it when thinking of related things.

For example, the best physicians are better at diagnosing illnesses because they tend to think in classes of diseases with shared features rather than isolated diseases with unique symptoms, and they can quickly remember related diseases with similar symptoms.
Here’s an example of the power of structured knowledge. Suppose this is your grocery shopping list. If you accidentally leave this list at home, would you remember everything on it? Not likely, because it’s more than the three or four items that you can retain in your working memory at one time.

Suppose that you had organized your list alphabetically. Would that have helped you remember? It has structure, but the structure doesn’t really help much with the bottleneck of four items in working memory.

This categorization is an example of how novices structure knowledge. They latch on to surface features of information (like the first letter of each item’s name). Psychologists call this surface processing of information.

Experts, in contrast, look for the meaning of the information, and use that to structure it. Here is the same list the way an expert shopper might structure it. It is organized into four groups by grocery store department. One can keep those four categories in working memory, and then remember the 1 – 3 items in the category once in that department. Note also that pain reliever and milk have been used as sub-categories to make the list even simpler.

Psychologists call this deep processing of information. Items are categorized and cross-linked by meaning, so they are more easily recalled in the situation where they are needed.
According to research, most of us intuitively try to learn from a textbook by simply rereading or highlighting it. To develop well-structured knowledge, try these techniques that have been shown by research to be more effective.

Find meaningful structure in the new information. Outline or mindmap the material you have read. This helps you see relationships and categories.

Relate what you have read to what you already know. Ask yourself how it is related, and how it is similar or different. What analogies do you see? Ask yourself in what situations this new information would be useful. This helps you build connections between your exiting memories and the ones you are forming now, and helps substitute a bit for the lack of direct experience.

Try to explain what you have read to yourself or someone else. This will help you practice recalling it and show you what you have and have not understood.

Try to picture the new ideas, events, or processes in your mind. Visualization activates more of the brain than words.
Repeated Activation

When we learn implicitly, we remember the things we experience repeatedly because the same patterns of neurons fire frequently and the connections between them get stronger. This happens over periods of months and years. Most of us have driven a car so often that the procedures have been well-learned and are performed almost unconsciously.

When we learn explicitly, the experience is indirect and limited in frequency. So we have to substitute deliberate recall practice for repeated experience.

Most of us practice too little, and we practice just before the exam. This graph shows the results of a classic experiment. Three groups read the same text. One group read it four times, one group read it three times and took one practice test, and one group read it once and took three practice tests. When the final exam was given 5 minutes later, the students in the read only group scored the best. But when the exam was given a week later, the students in the three practice test did best. Practice testing is the best strategy for building long-term memory.

Practice recalling what you have learned by testing yourself. Research shows that this is most effective if you space the practice sessions out over days and weeks and study other material in between practice sessions.

Practice recalling what you have learned by trying to apply it in as many different situations as you can imagine.

The effect of practice testing is one of the most robust research findings of all that I will mention today.
Deliberate Learning
Alberto G., 2006. CC BY 2.0 (https://creativecommons.org/licenses/by/2.0/)

When we learn implicitly, our emotional system guides us unconsciously. If our actions result in pleasure, our brains strengthen the related memories. If our actions result in pain, we remember to avoid those behaviors.

Explicit learning requires us to take conscious control of our learning processes. Studies have shown that students who spend time thinking about how they are learning and monitoring their progress are more likely to perform better in courses. Unfortunately, research also shows that, on average, we are not very conscientious or good at this.

In one study, for example, students who had just taken a test in their psychology course were asked to estimate what their grade would be. Most students over-estimated their performance, and the students with the worst scores over-estimated the most.

Reviews of the research on feedback during learning conclude that it has a powerful effect if used properly. One researcher, John Hattie, uses the analogy of a GPS device to explain. The GPS device knows your destination and tells you where you are and what you need to do to get to your destination from there.

You can help yourself monitor and improve your own learning by using the GPS method. Periodically reflect on the answers to these questions:

1. What am I trying to learn?
2. What have I learned to this point?
3. What do I need to do next?

Goals and Feedback

What, specifically, am I trying to learn? Most courses list learning objectives in the syllabus, and most textbooks start chapters with learning objectives. The course objectives are what you must learn. Think also about what you want to learn and why.
The more ways you value what you are learning, the more effort you are likely to make.

**Where am I relative to my learning goals?**
Look at the feedback from your instructor on your exams and assignments. Ask a friend in the same course for their opinion. Research clearly shows that we are not very good at seeing our own weaknesses, blind spots, and false assumptions. We are much better at seeing them in others because we can be more objective. Honest, helpful feedback is one of the kindest gifts we can give each other.

**What do I need to do next?**
If you are making good practice, keep doing what you have been doing. If not, what learning strategies did you use? Were they effective? If not, what other learning strategies could you try? If you need help with this, don’t hesitate to talk to your instructor.

Here’s what we have talked about:
We are natural learners and achieve much implicit learning with little effort. Repeated experiences cause physiological and anatomical changes that strengthen connections between constellations of neurons representing information about the experience in memory. Academic learning is explicit and artificial. It requires effort to find meaning in abstract knowledge, to practice recall in lieu of repeated experiences, and to monitor and adjust our learning processes.

In other words, explicit learning takes work.
This is a worksheet from one of my current learning projects. I am learning Marathi, an Indian language that is my wife’s mother tongue. I spend a lot of time understanding the grammatical rules with my teacher and relating them to other languages I know. I practice (but not nearly enough), and then I test what I think I have learned by trying to speak with my wife, and she gives me feedback. I enjoy learning a new language, but it is tiring, and I have to admit that I was glad to have the excuse of preparing this presentation to skip class for the past couple of weeks.

All of us, including those of us who teach, are also learners, and we all know that it can be hard work. I hope you now better understand why it takes effort, and what kinds of effort are going to be most productive.

I would like to end with two areas of research that I find inspiring.

The first is about the magic of prior knowledge. What we perceive and learn from the world depends heavily on what we already know. In general, we perceive what we expect to perceive. When we encounter something we haven’t experienced before, it can be difficult to make sense of it. Extensive studies have consistently shown that prior knowledge is a better predictor of learning success than many other factors, including intelligence.

Although this means your first learning experiences with a new subject area will be difficult, it also means that learning gets easier as you master more and more knowledge about a subject. Learning accumulates like compound interest. The more you learn, the easier it is to learn.
more. Keep this in mind as you build your careers. You are going to become more and more expert in your chosen area, and you are going to be able to learn and perform at higher and higher levels.

There is also a body of research about the pleasures of achieving total absorption in your work, to the point that you lose consciousness of the world around you, you lose track of time, and the work is pure pleasure. This can happen during learning. It has happened many times as I pursued my interest in learning research. My wish for you is that you find a subject that so captivates you that you willingly devote uncounted hours toward learning and mastering that body of knowledge. I hope each of you finds your passion and experiences the pleasures of flow in your academic life.