SCIENCE OF LEARNING / OVERVIEW

How to structure learning to make it sustainable

the education hub

Summary

As teachers, we want our students to learn effectively and remember what they have learned in the future. What are the basic neural systems that allow us to learn and remember? Can we utilise our understanding of these systems to shape our teaching in the classroom? Here, we explore the two major systems, long-term memory and working memory, explaining their key features, and how they interact to allow us to learn and remember, and what it is important to consider when teaching new material to new students.

How information is stored in the brain

The function of the brain is to receive signals from the environment, to process them and to respond effectively to support well-being and survival. To react effectively, we rely on our long-term memory system, which stores the most important information from similar past scenarios.

The information is stored in neuronal patterns. Neurons are the basic functional unit in the brain, and they communicate with each other by sending and receiving signals. By activating each other they form pathways and networks of synchronous activity. These patterns represent our stored knowledge.

Specific patterns are created during learning, then stabilised and stored in long-term memory, and, potentially, reactivated upon recollection.

When we retrieve a memory, we are able to manipulate it, to think about it, to add new information to it, and to make decisions based on it. All of these functions are performed in another "mental space" or system called working memory.

Research indicates that the way we engage with information in our working memory influences how well this memory will be stored in the long-term memory system.

Working memory

The working memory is where all our mental processing takes place, our real-time thinking. It is where we combine incoming information with retrieved information from our long-term memory, and then use these two to make a decision or action.

The most prominent feature of the working memory system is its limited capacity. We are able to handle only a small number of items at any given moment. Many people have been taught the 7±2 items limit (i.e. that the normal range of items held in working memory is 5 to 9 items). However, research shows that this capacity is actually lower and is closer to just 4 items! You can experience the limited working memory capacity and experience how it decreases when required to handle unfamiliar items (undefined shapes) compared with familiar ones (digits) by going to this website: http://gocognitive.net/demo/working-memory capacity.

The most important points to remember about working memory are:

- It is where thinking takes place: connecting incoming new information with prior knowledge, and where both are manipulated.
- It has a limited capacity.
- Overload leads to information loss – either incoming information will not be processed, or an item 'in process' will be dropped for a new one.
- Processing in working memory is essential for long-term storage – it is the information's 'entry ticket' to the long-term memory storage, or in the words of Professor Daniel Willingham, "Memory is the residue of the thought"[1].

How processing in the working memory can support better long-term memory

A classic experiment showed that meaningful processing in the working memory is essential for later recall[2]. In the experiment, participants sat in front of a computer screen, where single words flashed for a brief moment (just long enough to read). Following each word, participants answered a yes/no question about the word that just appeared. There were three types of questions: shape related (is it written in lowercase or uppercase letters), sound related (does this word rhyme with…), and meaning related (is this part of a category, or does it belong in a sentence). The participants had to respond "yes" or "no" to these questions.

Shortly afterwards, the participants were asked to write down the words they remembered from the list.

Strikingly, the type of question determined the future ability to recall the words. Words followed by a question that required meaningful processing (i.e. Is a lion a mammal?), were much better remembered than words that required processing of sound (e.g. rhyming) or shape (e.g. case). This experiment supported the "levels of processing model of memory"[3], asserting that the kind of processing we do in the working memory is a key feature for future memory recall. It is not the number of times we come across a piece of information, but how deeply we had processed the information.

Making meaning

To ensure effective learning, it is essential to understand how to use the limited capacity of the working memory in the best possible way, at every learning stage.

There are four basic stages of learning: knowing, understanding, using and mastering.

Imagine a concept (word, object) that you have never encountered before, and it was not represented in your brain (left panel). Following the first encounter, the new concept is represented in the brain and connections re-formed between neurons to create a network. You may be able to recognise this concept in the near future, but not much more. It is something you just know.

In the next stage, the now familiar concept is explained. We make meaning by connecting the new concept to other concepts (words, objects, procedures, etc.) that we are already familiar with. If this was successful, we can say that we now understand this concept.

Next, we practise what we have learned. We try to recall the concept and, by doing so, we build pathways that will allow us to use this concept in the future.

If we repeat the process of making meaning and practise repeatedly in various ways and conditions, we can get to the point where we master the concept. We are able to use it easily and quickly, even automatically. This state of concept representation is described as a "schema" – it characterises the knowledge representations of experts.

How much of the working memory capacity does it take?

When we just know a concept (e.g. hearing a new word), there is not much we can do with it. When we understand it (e.g. learned the meaning of the word), using the concept is effortful as we need to reconstruct the meaning in order to use it, and to continuously hold it in the working memory. As we practise the concept repeatedly, it becomes easier to use it in various situations, and the load on the working memory is reduced. Once the concept is mastered (e.g. when a word is fully integrated into our vocabulary), using it becomes effortless, and it requires minimal working memory resource.

It's important to remember that learning is hard work and that building associations during learning and in practice requires most of our working memory resources. But it is worth it1. When a concept is well-practised, using it requires minimal working memory resources, which frees up resources to deal with a more complex task. Research shows that learning new information based on a well-established schema is much quicker and easier[4]. We know this from our experience too – students with established background knowledge learn new related information more quickly and easily. That's why drawing on students' prior knowledge when engaging in a new topic or skill is useful to the learning process.

Teaching with working memory in mind

As teachers, we hope our students will master the concepts we are teaching them so that they are able to use them freely in the future. In the learning phase invest effort in creating meaningful connections to prior knowledge. Make sure you explain information clearly and give concrete examples. Attempting more complex activities at this stage may result in overload.

In the practice phase, focus on using the information and building retrieval pathways to make it accessible for future use.

These points are critical because often they are not in line with our intuition. In the learning phase we often wish to engage and motivate the students to learn, and present real life problems or discovery-based tasks. It is important to consider if these activities might distract students from the main learning goal, and whether the students have enough working memory resources to engage in effective learning. It is important to verify what the students have learned and not take their engagement as a sole measure for learning (see details below). Often problem-based learning is more effective in the practice phase.

In the practice phase, our intuition may work in the opposite direction: we may enjoy and appreciate effortless methods of rehearsing the material which show fast gain, and not invest enough effort and working memory resources to build retrieval pathways for future use.

Focusing working memory resources on learning

Cognitive load theory[5] is a set of ideas supported by evidence that builds on the understanding of human cognitive architecture described earlier, developing instructional techniques and recommendations. The theory describes a series of effects that characterise the ways in which novice and expert learners learn new material, and emphasises the dramatic consequences of differences in background knowledge and processing resources. Here are some important guidelines:

1. Fully guided instruction recommended for novice students

Novice students have limited background knowledge in a field, and must devote most of their working memory resources to any new learning. As teachers we want to focus their efforts on the new ideas being learned, avoiding any unnecessary load. Consequently, novice students benefit most from direct and explicit instruction when learning new material. Research shows that "inquiry based learning" often disregards the limitations of working memory, and should not be used in the initial learning phases of novice students. At later stages, when the students are familiar with the basic concepts, and have practised them, they may benefit from more complex forms of learning, which allow them to develop their schema structures. As teachers, it is important to define learning goals and teaching approaches that match the students' phase of learning.

2. Choosing the best mode of presentation

It is important to consider how we present new information, especially when combining visuals with text or speech. Cognitive load theory offers some guidelines:

- Present all the information needed for a task in one place – going back and forth between a few sources, like a figure and a written explanation is adding unnecessary cognitive load.
- Don't use two forms of presentation to say the same thing – if you include written text, don't read it aloud.
- Combining visuals with verbal information is helpful and may enhance processing. It is important to remember that the visuals should be pictures or drawings, not text, and they should be directly related to the learned concept. Their purpose is not "just to draw attention", but to support the processing. Using visuals that are not directly related will achieve the opposite.

References

1 Willingham, D. T. (2009). *Why don't students like school?: A cognitive scientist answers questions about how the mind works and what it means for the classroom*. John Wiley & Sons.

Highly Recommended Reading, you can find the specific topic mentioned above here:

Chapter 3: Memory is the residue of the thought, on the importance of meaningful processing.

Chapter 5: Is Drilling worth it? on the essential role of practice.

Chapter 6: Cognition early in training is fundamentally different from cognition late in training.

2 Craik, F.I.M., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. Journal of Experimental Psychology: General, 104, 268-294.

3 Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal behavior*, 11, 671-684.

4 Shing, Y. L., & Brod, G. (2016). Effects of prior knowledge on memory: Implications for education. *Mind, Brain, and Education*, 10(3), 153-161.

5 Cognitive load theory: Research that teachers really need to understand (2017) by the Centre for Education Statistics and Evaluation, State of New South Wales (Department of Education).

https://www.cese.nsw.gov.au/images/stories/PDF/cognitive_load_theory_report_AA1.pdf

6 Clark, R., Kirschner, P. A., & Sweller, J. (2012). Putting students on the path to learning: The case for fully guided instruction. American Educator https://www.aft.org/sites/default/files/periodicals/Clark.pdf

Blogs and Links

Learn How To Study Using... Dual Coding by Megan Smith (Sumeracki) & Yana Weinstein via The Learning Scientists
http://www.learningscientists.org/blog/2016/9/1-1

Weekly Digest #89: Cognitive Load via The Learning Scientists
http://www.learningscientists.org/blog/2017/12/10/weekly-digest-89?rq=cognitive%20load%20theory

Weekly Digest #67: Dual Coding in the Classroom via The Learning Scientists
http://www.learningscientists.org/blog/2017/7/9/weekly-digest-67?rq=dual%20coding

Dual coding downloadable poster via The Learning Scientists
http://www.learningscientists.org/dual-coding

Cognitive Load theory Effects via Teaching HOW2s
https://teachinghow2s.com/docs/Cog_Load_Theory_Poster.pdf

