Working memory and its role in teaching and learning

School resources

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? This guide explores the two major systems, long-term memory and working memory, explaining their key features, 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 in order to support wellbeing and survival. Our ability to respond effectively is dependent on our long-term memory system to store important information from similar past scenarios. This 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. When they activate each other, they form pathways and networks of synchronous activity. These patterns represent our stored knowledge.

Specific patterns are created during learning, processed in our working memory before being 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 our 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 and real-time thinking takes place. It is where we combine incoming information from the environment with retrieved information from our long-term memory, and then use both to make a decision or complete an action. The most prominent feature of the working memory system is its limited capacity. We are able to handle only a small number of new items at any given moment. While it was originally thought that the normal range of items held in working memory is 5 to 9 items, research has shown that this capacity is actually lower and is closer to just 4 items.

The most important points to remember about working memory are:

- It is where thinking takes place, where incoming new information is connected 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: as Professor Daniel Willingham puts it, memory is the 'residue of 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 participants' future ability to recall the words. Words followed by a question that required meaningful processing (for example, 'is a lion a mammal?') were much better remembered than words that required processing of sound or shape. This experiment supports the levels of processing model of memory[3] which asserts that the kind of processing we do in the working memory is a key factor in future memory recall. It is not the number of times we come across a piece of information but how deeply we process the information that determines the extent of our ability to recall it in future.

Making meaning

To ensure effective learning, it is essential to understand how to use the limited capacity of the working memory in the most effective 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 therefore is not encoded in your brain. Following the first encounter, the new concept is now stored in the brain and connections have re-formed between neurons to create a network. At this level of learning, you may be able to recognise this concept in the near future, but not much more. It is something you **know but don't yet understand.** In the next stage, the now familiar concept is explained. We make meaning by connecting the new concept to other concepts (words, objects, procedures) with which we are already familiar. If this is successful, we can say that we now **understand the concept**.

Next, we practise what we have learned. We try to recall the concept and, by this act of retrieval, we build pathways that will allow us to **use the 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 storing or encoding of concepts in long-term memory is described as a 'schema' and it characterises the knowledge representations of experts.

How much of the working memory capacity does it take?

When we just know a concept (such as when we hear a new word), there is not much we can do with it. When we understand it (for example, when we have 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 (for example, when a word is fully integrated into our vocabulary), using it becomes automatic or effortless, and it requires minimal working memory resource.

It is important to remember that, while learning is hard work and that building associations during learning and in practice requires most of our working memory resources, it is worth it[4]. When a concept is well-practised, using it requires minimal working memory resources, freeing 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[54]. Students with established background knowledge learn new related information more quickly and easily, which is why drawing on students' prior knowledge when engaging in a new topic or skill is beneficial to the learning process.

Teaching with working memory in mind

Effective teaching leads to students mastering the concepts they are taught so that they are able to use them freely in the future. In the learning phase, it is important to invest effort in creating meaningful connections to prior knowledge, explaining information clearly and giving concrete examples. Attempting more complex activities at this stage may result in overload. 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 by presenting real life problems or discovery-based tasks. It is important to consider whether these activities might distract students from the main learning goal, and whether the students have sufficient working memory resources to engage in effective learning. Teachers should verify what the students have learned and not take their engagement as a sole measure for learning (see details below).

In the practice phase, focus on using the information and building retrieval pathways to make it accessible for future use. In this 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. Often problem-based learning is more effective in the practice phase.

Focusing working memory resources on learning

Cognitive load theory[6] is a set of ideas supported by evidence that builds on the understanding of human cognitive architecture to develop 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. Below are some important guidelines from cognitive load theory.

Fully guided instruction is 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. Teachers should focus students' efforts on the new ideas being learned and avoid any unnecessary load. Decades of research have demonstrated that novice students benefit most from direct and explicit instruction when learning new material[7]. While inquiry-based learning and similar approaches are common and widely promoted in schools, they should not be used in the initial learning phases of novice students because they impose too great a load on working memory resources. At later stages, when students are familiar with the basic concepts and have practised them, they may benefit from more complex forms of learning such as inquiry or problem-based learning that allow them to develop their schema structures. It is important for teachers to ensure that learning goals and teaching approaches are appropriate to the student's stage of learning.

Choose the best mode of presentation

It is important to consider how to 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, adds unnecessary cognitive load
- Don't use two forms of presentation to say the same thing – for example, if you include written text, don't read it aloud
- Combining visuals with verbal information is helpful and may enhance processing, but 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.

Recommended further reading

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.

It is based on research and written especially for teachers, includes clear explanation, compelling examples and demonstrations (some of which can be shared with students as well), and classroom applications. Specifically relevant are the following chapters:

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.

Harvard, B. (2017, December). Cognitive load theory and applications in the classroom. NOBA. https://nobaproject.com/blog/2017-12-06-cognitive-load-theory-and-nbsp-applications-nbsp-in-the-classroom

Deans for Impact (2015). The science of learning. Austin, TX: Deans for Impact. https://deansforimpact.org/resources/the-science-of-learning/

Kirschner, P.A., & Neelen, M. (2017, May). Double-barrelled learning for young and old. 3-Star Learning Experiences. https://3starlearningexperiences.wordpress.com/2017/05/30/double-barrelled-learning-for-young-old/

Endnotes

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.

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 Willingham, 2009.

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

6 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-VR_AA3.pdf

7 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

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