BUILDING THE REALITIES OF WORKING MEMORY AND NEURAL FUNCTIONING INTO PLANNING INSTRUCTION AND TEACHING

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ABSTRACT

What are important take-home messages of a learning brain for teachers? This session considers this question, initially, by briefly focusing on the current theory constructs of working memory, long-term memory, neural connections and why evolution may have presented us with the type of brain we use today. When planning for teaching and learning the implications of these constructs need to be taken into account. But the activity of the brain does not happen in isolation of the personal, social or cultural context of the learning environment or of limitations within the brain associated with issues of cognitive load. Significantly, for optimal learning to occur, the teaching agenda should represent the reality of working memory and neural functioning. This means it is important for teachers to understand the implications of automaticity, a special kind of rehearsal referred to as deliberate practice, and the valuing of errors and the use of these errors as a source of building expertise. Alongside of this is the equally important emphasis on the role that consistent and sustained effort plays in learners achieving needed skills, knowledge and understandings.

INTRODUCTION

There are three key ideas for this paper:

- a theoretical construct of the learning brain
- neural functioning
- critical aspects of learning such as automaticity, deliberate practice and the role of errors in building expertise.

This paper describes these ideas briefly as background to the presentation.

A THEORETICAL CONSTRUCT OF THE LEARNING BRAIN

This part focuses on the current theory constructs of working memory, long-term memory, neural connections and why evolution may have presented us with the brain humans use today.

WORKING MEMORY

Working memory is a theoretical construct attributed to Baddeley (Baddeley & Hitch, 1974) and grew out of ideas associated with the workings of short-term memory. The two terms, working memory and short-term memory, are often considered synonymously but working memory is a more holistic concept associated with temporary storage of information of which short-term memory is but a part.

Working memory is not conceived as a single structure. In its current form (Baddeley, 2007) it has a central executive controlling system, two mode-specific components and a temporary memory store.

The 'central executive' part of working memory occurs mainly in the prefrontal cortex (but not uniquely as patterns of neural activity have been identified in the frontal and parietal lobes). Its functions include holding information input for a short time and also retrieving information from other parts the brain, and manipulating these aspects. The central executive system also controls two neural loops, one for visual data that activates areas near the visual cortex and is referred to as a 'visuospatial sketchpad', and one for language that uses Broca's area as a kind of inner voice, referred to as the 'phonological loop'. The temporary memory, referred to as the 'episodic buffer', holds data provided by the two neural loops, links to the central executive system and plays a critical role in conscious awareness.

In overview, working memory capacity is the brain's ability to hold information in the mind while transforming it or other information. It is where information is organised, contrasted and compared. Significantly, working memory is limited in capacity and duration. As we become more expert in a task, our working-memory size does not increase. Instead we become more efficient as our brain chunks individual aspects, enabling us to increase the information on which we can focus.

LONG-TERM MEMORY

Long-term memory is where knowledge is held. The process of laying down long-term information differs in both a structural and a functional sense from that of working memory. Permanent changes in neural networks are associated with long-term memories.

The amount of information that can be stored in long-term memory appears to be unlimited. Once information is laid in long-term memory it appears stable, although some recent research points to challenges to this idea in a small number of specific circumstances. Significantly, once strong neural connections are established in long-term memory, for most practical purposes they remain available for activation given appropriate circumstances.

While forgetting does happen to information held in long-term memory, it occurs at a slow rate and seems to depend on the amount of use and breadth of the neural connections. Forgetting is usually not about the loss or disestablishment of a neural network but that it has become increasingly difficult to access.

NEURAL NETWORKS

Numbers of single neurons (nerve cells) link together to form neural networks or pathways. Neurons are nerve cells that transmit information through an electrochemical process in which a signal using neurotransmitters is sent from one neuron over a small gap (a synaptic cleft) to receptors of another neuron that receives the information.

Our brain contains 10^{11} neurons and each neuron in the brain can link with as many as 10 000 other neurons. The brain stores information in neural networks and the existence of a memory comes about through the activation of a network of many interconnected neurons.

It was Donald Hebb who stated that if two neurons are active at the same time, the synapses between them are strengthened:

> *When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased. (Hebb, 1949, p. 62)*

This quote is often referred to as Hebb's law and paraphrased as: Neurons that fire together (over time) wire together. It is saying that with repeated use, the efficiency of synapse connections increases, facilitating the more efficient passage of nerve impulses.

It was not until the 1970s that researchers identified the mechanism that supported Hebb's idea. Recent research has increased our understanding of the process of building neural networks; for example, efficiency of the connections is increased for neurons activated together and connections of a number of neurons into a single neuron enhances the strength of these connections.

EVOLUTION'S ROLE IN THE BRAIN

It has been suggested that there is an evolutionary advantage linked to the notion of a limited capacity working memory and the time and effort required to create neural networks in long-term memory.

The view here is that being able to pay attention through working memory to a limited number of aspects that were most important had a survival advantage. In the case of an attacking wild animal, selecting an appropriate action from a large number of diverse ideas would potentially interfere with the rapid decision-making needed for life preservation.

In terms of long-term memory there are also evolutionary advantages to its structure and mode of operation. The ability to lay new memories or replace old memories quickly is unlikely to be advantageous as there would be the possibility that certain fundamental and critical brain networks could be lost. This could or would render the individual at risk. Small changes occurring over time associated with effort also allow the opportunity for an individual to test the efficacy of what has been acquired.

OVERVIEW

Long-term memory is where permanent information is stored. This can be enhanced by both mental repetition of the information and by giving the ideas meaning, and associating the information with other previously acquired knowledge. Motivation is also a consideration in learning and material is more likely to be retained where there is strong learner interest.

Human intelligence comes from stored knowledge in long-term memory, not long chains of reasoning in working memory. Improved learning consists of building neural networks that either take existing networks and add further connections to them or combine separate neural networks into a larger network that can be activated holistically.

A neural network can hold large amounts of information as a simple unit in working memory. Higher order processing occurs when there is 'sufficient space' in working memory so that appropriate networks can be accessed from long-term memory and worked upon.

Through the limited capacity of working memory, the brain is designed to forget most of the data that comes through the senses. The brain does allow us to remember information that we practise and rehearse. But mere consolidation of knowledge in long-term memory does not guarantee that it will be able to be accessed indefinitely.

Storage of information into long-term memory depends on two issues. The first involves effort usually in the form of repetition or rehearsal. The second relates to storage and this works best if the material, concept or activity is understood at some level of meaningful association linked to an individual's experience.

Learning is linked to the plasticity of the neural networks in the brain. Neuroplasticity refers to the brain's ability to change by creating new or modified neural networks. This can occur by a number of ideas being found in one neural network distinguished through different patterns of neurons or by a single idea being found by the activation of different neural networks spread throughout the brain.

NEURAL FUNCTIONING

The activity of the brain does not happen in isolation of different contexts within which humans learn. Important contexts may be of a personal, social or cultural nature or of limitations within the brain associated with issues of cognitive load.

CONTEXT OF THE LEARNING ENVIRONMENT

The issue here is that learning takes place within certain contexts and these can have a huge impact on the brain and subsequently on the quality of the learning involved.

The work of Dweck (2006) offers insights into problems caused when instruction or belief systems do not support neural reality. In particular, the often-cited study where 400 fifth-grade students were praised for 'trying hard' as opposed to praising for 'innate intelligence' on a problem-solving task is most relevant.

According to Dweck, a series of experiments found that those students who were praised for intelligence (only in a single sentence) mostly chose to attempt more straightforward questions (when given a choice); showed increased stress levels on more difficult problems; and performed poorly when expected to undertake problems similar to the base-line experiment, than the group of students who were praised for their ability to work hard to solve the problems.

In follow-up interviews, Dweck found that those students who thought that intelligence was the key to success would downplay the importance of effort. Expending effort for them became a sign that they were not good enough. It also explains why those who were praised as 'intelligent' went for the more predictable questions and were less willing to take risks because they had more to lose if they failed.

COGNITIVE LOAD

George Miller in 1956 suggested that the number of bits of information that can be retained is about 7 +/– 2. This is often referred to as Miller's law. While this is often true of capable students, across the population it is probably closer to around four items (Cowan, 2001), although this can depend on context.

'Chunking' can lead to holding more information in working memory. Chunking is taking bits and combining them into more meaningful groupings (this is the reason we express phone numbers in groups of three or four as it reduces the cognitive load associated with remembering a long set of individual numbers). When chunking occurs, each new chunk becomes one of the 7 +/– 2 items.

When we talk of cognitive load in learning we are referring to the limits imposed by the finite capacity of working memory to undertake information processing and that changes to long-term memory occur slowly and incrementally. So a teacher needs to be conscious of several features including the complexity of the material to be acquired, how the material is to be presented or taught and the background experience and knowledge of the learner if optimum learning is to occur.

This last point requires further elaboration. In the case of learners acquiring new information, the limited capacity of working memory is a critical element to knowledge acquisition and places serious conditions on the learning environment.

In the case of learners working in familiar situations with organised information (in terms of elaborated schemas) laid down in long-term memory, the situation is different. For this experienced group of learners, while the number of chunks that can be retrieved to work on remains limited, the amount of material represented by a chunk can be substantial.

OVERVIEW

From a brain perspective, the notion of innate intelligence does not represent neural reality. To have information laid down in long-term memory requires at the very least practice, rehearsal and effort.

An important aim of teaching is to assist students to reduce the cognitive load associated with basic and routine tasks to facilitate deeper higher-order understandings. There are large processing demands associated with inefficient methods (such as finger counting or word decoding strategies), as opposed to direct retrieval approaches.

Learning is about establishing neural networks. Those networks where neurotransmitters can send nerve impulses efficiently between neurons results in improved memory recall and use. Further, in committing something to memory, just as in most other activities, how the material to be learned is organised is important. Understanding assists the brain with such organisation.

CRITICAL ASPECTS OF LEARNING

This part considers three critical aspects of learning related to the brain. These are automaticity; deliberate practice; and the valuing of errors and their use as a source of building expertise.

AUTOMATICITY

Automaticity is the ability to complete everyday tasks effortlessly without requiring conscious effort. In learning, automaticity becomes important when considering the acquisition and use of low-level or fundamental skills and higher order or advanced concepts.

In the case of lower order skills, automaticity frees up working-memory capacity. This involves a change in the neural networks activated, and an overall lessening of brain activity. In the case of higher order skills, more complex information takes a heavy toll on working-memory capacity. Given the limits of working-memory capacity it is critical that needed 'space' is not used up on basic tasks that preclude the brain from accessing or processing more advanced ideas. Hence, an important goal of education is not to distract the learning brain by an overemphasis on basic skills that should be automated.

In summary, with high consistency of processing speed and accuracy of responses, foundation skills can become automatic. As a result, more cognitive effort can be devoted to higher-order skills.

DELIBERATE PRACTICE

A special kind of rehearsal is referred to as deliberate practice. Much of the early work in this area is attributable to a study by Eriksson, Krampe and Tesch-Romer (1993).

Deliberate practice is an activity that is well structured and designed to improve the current level of performance. As the name suggests, it allows for repeated experiences in which the individual can attend to critical aspects of a task.

Within deliberate practice, specific activities are used to deal with identified errors or weaknesses within a context of feedback. People are motivated to exert effort on particular aspects of a task because the focused practice on these key aspects improves overall performance.

VALUING ERRORS

Errors play a critical role in the establishment and maintenance of neural networks and, consequently, in building expertise. There is an evolutionary take on this aspect that the brain appears to be especially organised to respond to mistakes in a 'positive' way in terms of learning outcomes.

Those ancestors who did take notice of incorrect decisions and changed their behaviour would have been more likely to survive. Hence one could envisage that incorporating lessons from the past into our future decision making was an important characteristic to acquire. The alternative, of course, is that one would continue to repeat past errors.

If we do not allow students in schools to experience the significance of the role errors and mistakes play in learning then we are setting them up for future failure as well as placing a ceiling on their learning. Learning from mistakes is how learners are challenged to do and look at things differently, and errors motivate the brain to try new approaches. Engaging in mistakes provides the environment for students to move to a deeper level of understanding.

Niels Bohr, the famous Danish physicist (1885–1962), once said 'an expert is a person who has made all the mistakes that can be made in a very narrow field'. The implication from this quote is that experts not only expect and accept mistakes, they seek them out to enhance their knowledge and understanding.

Success should not be measured by the number of times a learner has avoided mistakes but rather on the mastery of complex and important ideas. Education systems should not be seen as punishers of errors: such an approach does not represent the neural reality of learning. Rather, learning should be about acknowledging the critical importance of focusing on mistakes or errors and the value of educational risk taking where an error or mistake is a likely outcome.

CONCLUSION

That consistent and sustained effort plays a critical role in learners achieving needed skills, knowledge and understandings is an important message underpinning the ideas in this paper.

Working-memory capacity underlies a number of the problems students experience in acquiring competence or undertaking more difficult tasks. A critical step in supporting students is to provide them with experiences that enable them to reduce the cognitive load associated with processing basic skills so as to make way for higher order processing.

If teachers support students to replace effortful (high cognitive load) strategies with more strategic and less demanding approaches then their performances in learning will improve. All learning is also enhanced when children are encouraged to understand that making mistakes is a critical element for the brain in acquiring genuine understanding, knowledge and skills.

Evidence for the ideas expressed in this paper can be seen in the QuickSmart Numeracy and Literacy programs. These two programs draw heavily on ideas associated with the limits of working memory, the creation of strong neural networks, the valuing of mistakes and educational risk taking and motivation built on success in learning as setting the basis for higher-order skill and knowledge growth. Each year many thousands of students in schools throughout Australia undertake this program and experience substantial and sustained improvement on independent tests (for more information see http://www.une.edu.au/simerr/quicksmart/pages/).

By considering instruction through the constructs of a learning brain and, in particular, by building the realities of working memory and neural functioning into planning instruction and teaching, there is a real hope of genuine improvements in student learning. There is also the potential to have statements concerning 'students achieving their potential' to be more than just a glib mantra.

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