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Cognitive load theory: Research that teachers really need to understand

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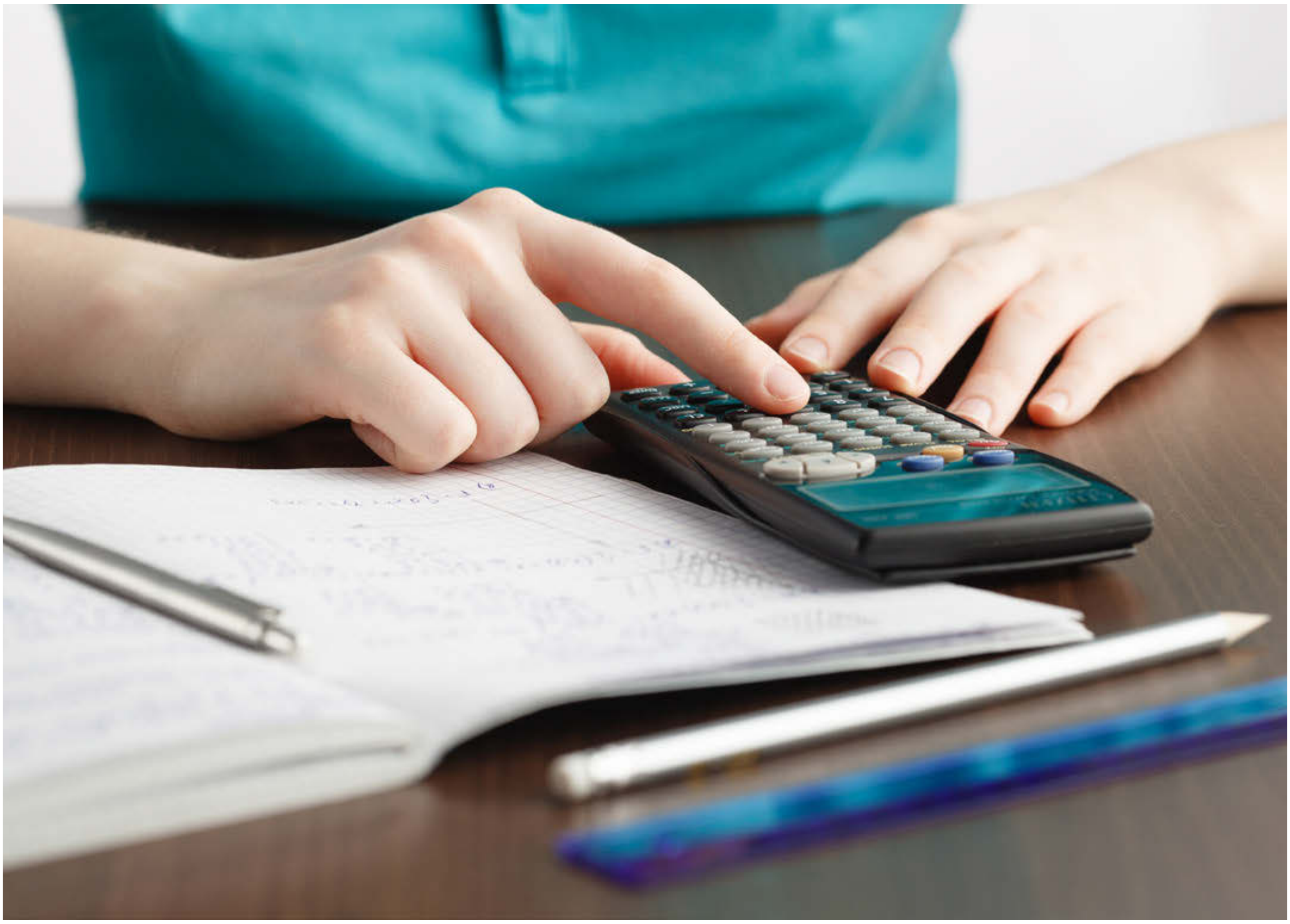

Why cognitive load theory?

To improve student performance, teachers need to understand the evidence base that informs and helps improve their practice. An area of research with significant implications for teaching practice is cognitive load theory. Cognitive load theory was recently described by British educationalist Dylan Wiliam as 'the single most important thing for teachers to know' (Wiliam 2017).

Grounded in a robust evidence base, cognitive load theory provides theoretical and empirical support for explicit models of instruction. Research in cognitive load theory demonstrates that instructional techniques are most effective when they are designed to accord with how human brains learn and use knowledge.

This paper describes the research on cognitive load theory and what it means for more effective teaching practice. The first part of the paper explains how human brains learn according to cognitive load theory, and outlines the evidence base for the theory. The second part of the paper examines the implications of cognitive load theory for teaching practice, and describes some recommendations that are directly transferable to the classroom.

What is cognitive load theory?

Cognitive load theory is built upon two commonly accepted ideas. The first is that there is a limit to how much *new* information the human brain can process at one time. The second is that there are no known limits to how much *stored* information can be processed at one time. The aim of cognitive load research is therefore to develop instructional techniques and recommendations that fit within the characteristics of working memory, in order to maximise learning.

Cognitive load theory supports explicit models of instruction, because such models tend to accord with how human brains learn most effectively (Kirschner, Sweller & Clark 2006). Explicit instruction involves teachers clearly showing students what to do and how to do it, rather than having students discover or construct information for themselves (see Centre for Education Statistics and Evaluation 2014, pp. 8-12). Hattie summarises explicit instruction as an approach in which:

> *The teacher decides the learning intentions and success criteria, makes them transparent to the students, demonstrates them by modelling, evaluates if they understand what they have been told by checking for understanding, and retelling them what they have been told by tying it all together with closure.*
>
> (Hattie 2009, p. 206)

Cognitive load theory emerged from the work of educational psychologist John Sweller and colleagues in the 1980s and 1990s (see especially Sweller 1988, 1999). They assert:

> *The implications of working memory limitations on instructional design can hardly be overestimated … Anything beyond the simplest cognitive activities appear to overwhelm working memory. Prima facie, any instructional design that flouts or merely ignores working memory limitations inevitably is deficient.*
>
> (Sweller, van Merrienboer & Paas 1998, pp. 252-253)

Cognitive load theory is based on a number of widely accepted theories about how human brains process and store information (Gerjets, Scheiter & Cierniak 2009, p. 44). These assumptions include: that human memory can be divided into working memory and long-term memory; that information is stored in the long-term memory in the form of schemas; and that processing new information results in 'cognitive load' on working memory which can affect learning outcomes (Anderson 1977; Atkinson & Shiffrin 1968; Baddeley 1983).

How the human brain learns

In order to understand cognitive load theory, it is necessary to understand how working memory and long-term memory process and store information.

Working memory is the memory system where *small* amounts of information are stored for *a very short duration* (Peterson & Peterson 1959)[1]. Working memory roughly equates with what we are conscious of at any one time. Clark, Kirschner and Sweller call it 'the limited mental "space" in which we think' (2012, p. 8). Research suggests that an average person can only hold about four chunks of information in their working memory at one time (Cowan 2001), although there is evidence to indicate differences in working memory capacity between individuals (see, for example, Barrett, Tugade & Engel 2004).

Long-term memory is the memory system where *large* amounts of information are stored *semi-permanently* (Atkinson & Shiffrin 1968; Tulving 1972). Clark, Kirschner and Sweller call long-term memory 'that big mental warehouse of things (be they words, people, grand philosophical ideas, or skateboard tricks) we know' (2012, p. 8).

Cognitive load theory assumes that knowledge is stored in long-term memory in the form of 'schemas'[2]. A schema organises elements of information according to how they will be used. According to schema theory, skilled performance is developed through building ever greater numbers of increasingly complex schemas by combining elements of lower level schemas into higher level schemas. There is no limit to how complex schemas can become. An important process in schema construction is automation, whereby information can be processed automatically with minimal conscious effort. Automaticity occurs after extensive practice (Sweller, van Merrienboer & Paas 1998, p. 256).

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1 The term 'working memory' is occasionally used synonymously with 'short-term memory', although some theorists consider these two forms of memory to be distinct. See Cowan (2008) for an overview of the distinctions and similarities between various key theories of short-term memory and working memory.

2 Schema theory was introduced into psychology and education by Frederic Bartlett (1932) and Jean Piaget (1928), and further developed by educational psychologist Richard Anderson (1977, 1978).

Learning to read is a good example of schema construction and automation. Children begin to learn to read by constructing schemas for squiggles on a page – letters. These simple schemas for letters are used to construct higher order schemas when they are combined into words. The schemas for words, in turn, are combined into higher order schemas for phrases and sentences. This process of ever more complex schema construction eventually allows readers to scan a page filled with squiggles and deduce meaning from it. With extensive practice, readers can derive meaning from print with minimal conscious effort (Sweller, van Merrienboer & Paas 1998, pp. 255-258)[3].

Schemas provide a number of important functions that are relevant to learning. First, they provide a system for organising and storing knowledge. Second, and crucially for cognitive load theory, they reduce working memory load. This is because, although there are a limited number of elements that can be held in working memory at one time, a schema constitutes only a single element in working memory. In this way, a high level schema – with potentially infinite informational complexity – can effectively bypass the limits of working memory (Sweller, van Merrienboer & Paas 1998, p. 255).

If working memory is overloaded, there is a greater risk that the content being taught will not be understood by the learner, will be misinterpreted or confused, will not be effectively encoded in long-term memory, and that learning will be slowed down (Martin 2016, p. 8). The automation of schemas reduces the burden on working memory because when information can be accessed automatically, the working memory is freed up to process new information (Laberge & Samuels 1974).

The limitations of working memory can be overcome by schema construction and automation. For example, try to remember the following combination of letters: y-m-r-e-o-m.In this case each letter constitutes one item, so you are being required to remember six items at once. Now try to remember the following combination of letters: m-e-m-o-r-y. In this case you are still required to remember the very same six items. However, because you have a schema in your long-term memory for the word 'memory', you are able to chunk the letters into just one item. Now your working memory is freed up to remember other items.

Types of cognitive load

Load type	Source	Effect on learning	Example
Intrinsic load	The inherent complexity of the material and the prior knowledge of the learner	Necessary to learning (but potentially harmful if too high, because it can cause cognitive overload)	Learning how to solve the mathematical equation *a / b = c, solve for a* Learning this equation might have a high intrinsic load for a novice maths student, but would have a low intrinsic load for an expert mathematician
Extraneous load	Poorly designed instruction that does not facilitate schema construction and automation	Harmful because it does not contribute to learning	The student is required to figure out how to solve the equation themselves, with minimal guidance from the teacher This imposes a high cognitive load, but does little to encourage schema construction because the student's attention is focused on *solving* the problem rather than on *learning* the technique
Germane load	Well designed instruction that directly facilitates schema construction and automation	Helpful because it directly contributes to learning	The student is explicitly taught how to solve the problem and given lots of worked examples demonstrating how to do it This imposes a lower cognitive load on the student, enabling them to learn and remember *how* to solve the problem when faced with it again

3 For a review of the research on effective reading instruction in the early years of school, see Centre for Education Statistics and Evaluation (2017). There has not been a substantial amount of research on how cognitive load theory can be used specifically to inform literacy instruction; an exception is Torcasio & Sweller 2010.

Types of cognitive load

Cognitive load theory identifies three different types of cognitive load: intrinsic, extraneous and germane load (see Sweller 2010; Sweller, van Merrienboer & Paas 1998). The three types of cognitive load are generally assumed to be additive – that is, intrinsic load + extraneous load + germane load = total cognitive load[4]. Cognitive overload occurs when the total cognitive load exceeds the working memory capacity of the learner (Gerjets, Scheiter & Cierniak 2009, p. 45).

Intrinsic

Intrinsic cognitive load relates to the inherent difficulty of the subject matter being learnt (Sweller 1994, 2010; Sweller & Chandler 1994). In simple terms, intrinsic load can be described as the 'necessary' type of cognitive load. Two factors influence intrinsic cognitive load: the complexity of the material, and the prior knowledge of the learner (Sweller, van Merrienboer & Paas 1998). This means that subject matter that is difficult for a novice may be very easy for an expert. For example, the task of learning to write the letters of the alphabet is likely to have a high intrinsic load for a child in the first year of school, but the same task would have a much lower intrinsic load for a child in the second or third year of school.

Many theorists agree that intrinsic cognitive load can be altered by instructional techniques that make complex material easier to learn. One way to lower the intrinsic cognitive load of material is the 'simple-to-complex' approach, where the elements of the material are introduced to the learner in a simple-to-complex order so that the learner does not initially experience the full complexity of the material (van Merrienboer, Kirschner & Kester 2003). A second method is the 'part-whole' approach, where the individual elements of the material are introduced to the learner first, before the integrated task is introduced (Bannert 2002; Pollock, Chandler & Sweller 2002). A third approach is to introduce the material in its full complexity from the beginning, but then to direct the attention of the learner to the individual interacting elements (van Merrienboer, Kester & Paas 2006). Van Merrienboer and Sweller (2005) state that both simple-to-complex and part-whole approaches work to reduce the cognitive load of learners by introducing single, simple elements at the beginning, and gradually increasing complexity.

Extraneous

Extraneous cognitive load relates to how the subject matter is taught. According to van Merrienboer and Sweller, 'Extraneous cognitive load … is load that is not necessary for learning (i.e. schema construction and automation) and that can be altered by instructional interventions' (2005, p. 150). In simple terms, extraneous load is the 'bad' type of cognitive load, because it does not directly contribute to learning. Cognitive load theorists consider that instructional design will be most effective when it minimises extraneous load in order to free up the capacity of working memory.

> *A combination of high intrinsic and high extraneous cognitive load may be fatal to learning because working memory may be substantially exceeded … [I]t may be essential to design instruction in a manner that reduces extraneous cognitive load.*
>
> (Sweller, van Merrienboer & Paas 1998, pp. 263-264)

Theorists of cognitive load have identified a number of instructional approaches that work to reduce extraneous cognitive load in order to increase the efficacy of instruction (van Merrienboer and Sweller 2005, p. 151). Some of these will be described in the final section of the paper.

Germane

Germane cognitive load refers to the load imposed on the working memory by the process of learning – that is, the process of transferring information into the long-term memory through schema construction (Sweller, van Merrienboer & Paas 1998, p. 259). For this reason, germane cognitive load can be understood in simple terms as the 'good' type of cognitive load.

Theorists of cognitive load assert that instructional material has maximum effectiveness when it reduces extraneous load (which is not relevant to learning) and increases germane load (which is directly relevant to learning). Gerjets, Scheiter and Cierniak explain that germane load is 'caused by a supportive instructional design and is helpful for effective learning' (2009, p. 45).

> *The combination of decreasing extraneous cognitive load and at the same time increasing germane cognitive load involves redirecting attention: Learners' attention must be withdrawn from processes that are not relevant to learning and directed towards processes that are relevant to learning and, in particular, toward the construction and mindful abstraction of schemas.*
>
> (Sweller, van Merrienboer & Paas 1998, p. 264)

Theorists of cognitive load generally consider intrinsic, extraneous and germane load to be additive (Paas, Renkl & Sweller 2003, p. 2). For this reason, the approach of decreasing extraneous cognitive load while increasing germane cognitive load will only be effective if the total cognitive load remains within the limits of working memory (Sweller, van Merrienboer & Paas 1998, p. 264).

4 In response to discussions regarding problems of defining and measuring the different types of load (for example, Schnotz & Kürschner 2007), some cognitive load theorists have recently suggested a reformulation of the idea that there are three separate and additive forms of load. This reformulation suggests a return to a dual framework in which intrinsic and extraneous load are defined as the two primary types of cognitive load and are considered additive. Germane load is re-defined in terms of intrinsic load – it refers to the working memory resources devoted to dealing with intrinsic load, and is not considered additive (Sweller 2010; see also Kalyuga 2011). For clarity, however, the three types of load are considered separate and additive in this literature review.

What is the evidence base for cognitive load theory?

Cognitive load theory is supported by a significant number of randomised controlled trials (RCTs). This large body of evidence indicates that instruction tends to be more effective when it is designed according to how human brains process and store information.

The 'worked example effect' is one instructional approach recommended by cognitive load research that is supported by a substantial number of RCTs[5]. The worked example effect was first demonstrated in the 1980s (Cooper & Sweller 1987; Sweller & Cooper 1985). In one early study, Cooper and Sweller (1987) designed a series of experiments in which high-school maths students were required to learn how to solve a range of simple algebra problems. They found that students who were taught using lots of worked examples learnt more quickly than students who were required to solve the problems themselves. Further, they found that the students taught using worked examples were not only better able to solve *similar* problems on subsequent tests, but were also better able to solve 'transfer problems' in which the same algebraic rules they had learned needed to be applied in different contexts. The effect has since been replicated in a large number of RCTs (for example, Bokosmaty, Sweller & Kalyuga 2015; Carroll 1994; Kyun, Kalyuga & Sweller 2013; Paas 1992; Paas & van Merrienboer 1994; Pillay 1994; Quilici & Mayer 1996; Tuovinen & Sweller 1999). In a meta-analysis of studies on the effectiveness of worked examples, Crissman (2006) found an effect size of 0.52.

The majority of studies in cognitive load research do not attempt to *directly* measure cognitive load itself, but rather aim to measure the effectiveness of instructional techniques designed to accord with the limitations of working memory. Studies of this type typically consist of a control group that receives a learning intervention using conventional techniques (for example, using independent problem-solving to learn a new skill), and a treatment group that receives a learning intervention using cognitive load techniques (for example, using worked examples to learn a new skill). Both groups are then tested to assess the effectiveness of the intervention. The test performance of participants is taken as an *indirect* measure of cognitive load, with high results on post-tests considered to indicate that cognitive load was successfully managed (for example, Mayer et al. 2005; Stull & Mayer 2007). It is worth noting that key proponents of cognitive load theory themselves acknowledge the need to identify a reliable means of directly measuring cognitive load, in order to develop a more empirical basis to support the theory (for example, Paas, Renkl & Sweller 2003, p. 4; Paas et al. 2003, p. 64).

Some studies do attempt to directly measure the cognitive load imposed by different instructional techniques, with varying reliability (for an overview, see de Jong 2010; Paas et al. 2003). There are a variety of methods for attempting to measure cognitive load. One approach is to use physiological techniques such as measures of heart activity (for example, Fredericks et al. 2005; Paas & van Merrienboer 1994), brain activity (for example, Murata 2005; Smith & Jonides 1997) or eye activity (for example, Schultheis & Jameson 2004; van Gerven et al. 2004). Another approach is to use dual-task techniques, in which a secondary task is introduced in addition to the main learning task, and impaired performance in the secondary task is taken to indicate higher cognitive load (for example, Brünken, Plass & Leutner 2003; Chandler & Sweller 1996). The majority of studies that attempt to measure cognitive load use subjective techniques such as rating scales, in which participants are asked to indicate the level of cognitive load experienced (for example, Paas 1992; Paas, van Merrienboer & Adam 1994).

Questions around cognitive load research

The *broad* assumptions of cognitive load theory – that the capacity of working memory is limited, and that learning is most effective when it is designed to accommodate these limitations – is generally not contested. It is worth noting, however, that a number of scholars have raised questions regarding some of the *specific* assumptions of the theory. These questions generally fall into three categories: problems with the definitions of cognitive load, concerns about the methodological rigour of the research, and issues with its external generalisability.

In regard to the definitions of cognitive load theory, an important question is whether the three different types of cognitive load – intrinsic, extraneous and germane – can be clearly distinguished (de Jong 2010; Moreno 2010; Schnotz & Kürschner 2007). A second concern is whether the three types of cognitive load can indeed simply be added to determine the total cognitive load experienced by the learner (de Jong 2010; Moreno 2010; Park 2010), as has been claimed by cognitive load theorists (for example, Sweller, van Merrienboer & Paas 1998, p. 263; Paas, Renkl & Sweller 2003, p. 2). These concerns are important because, if the types of cognitive load cannot be clearly separated, it becomes difficult to make practical recommendations on how teachers can best manage 'good', 'bad' and 'necessary' load in a classroom environment[6].

In regard to the methodological rigour of studies, the lack of a direct measure of cognitive load is a key concern (Brünken, Plass & Leutner 2003; de Jong 2010; Moreno 2010; Schnotz & Kürschner 2007). The lack of empirical indicators to distinguish between and measure the different types of load (intrinsic, extraneous and germane) is also an issue (de Jong 2010; Gerjets, Scheiter & Cierniak 2009; Schnotz & Kürschner 2007; for attempts to overcome this see DeLeeuw & Mayer 2008; Leppink et al. 2014).

Finally, there are also concerns about whether cognitive load research is generalisable to realistic teaching environments. De Jong describes a range of problems with generalisability, including that cognitive 'overload' rarely occurs in realistic learning settings; that the very short study time used in most cognitive load studies does not reflect the kinds of tasks and study time that would occur in real settings; and that study conditions are often deliberately constructed to demonstrate particular effects that would rarely occur in real learning situations (2010, pp. 123-125).

5 For further detail on the 'worked example effect' see 'Types of cognitive load' table on page 3.

6 A more recent definition of the types of load suggested by Sweller (2010) may quell these concerns.

What does cognitive load theory mean for teaching practice?

Explicit teaching

The question of how people learn best has been the subject of significant debate, which can be broadly divided into two approaches to teaching practice. On one side are those who believe that all people learn best when allowed to discover or construct some or all of the information themselves (for example, Bruner 1961; Papert 1980; Steffe & Gale 1995). On the other side are those who believe that learners do best when they are provided with explicit instructional guidance in which teachers clearly show students what to do and how to do it (for example Klahr & Nigam 2004; Mayer 2004; Rosenshine 1986). Cognitive load theory provides theoretical and empirical support for the latter, explicit model of instruction. Leading theorists of cognitive load argue:

> *Decades of research clearly demonstrate that for novices (comprising virtually all students), direct, explicit instruction is more effective and more efficient than partial guidance. So, when teaching new content and skills to novices, teachers are more effective when they provide explicit guidance accompanied by practice and feedback, not when they require students to discover many aspects of what they must learn.*
>
> (Clark, Kirschner & Sweller 2012, p. 6, see also Kirschner, Sweller & Clark 2006)

It is important to note that cognitive load theorists do not advocate using *all* aspects of explicit instruction *all* the time. Indeed, they recognise the need for learners to be given the opportunity to work in groups and solve problems independently – but assert this should be used as a means for *practicing* newly learnt content and skills, not to *discover* information themselves (Clark, Kirschner & Sweller 2012, p. 6).

Andrew Martin (2016), for example, advocates a teaching model that is explicitly designed around cognitive load theory and the constraints of working memory. He suggests, however, that less structured approaches can also be an effective instructional method for students who are further along the novice/expert continuum *if* such instruction is designed with the constraints of working memory in mind.

> *These approaches are aimed at promoting learner independence while managing cognitive load appropriately, depending on the learner's novice/expert status … If the instructor provides some guiding principles, prior information, signposts along the way, and scaffolds and assistance where needed, there is less burden on working memory.*
>
> (Martin 2016, p. 39)

There is some research to suggest that managing the cognitive load of learners through explicit instruction may also contribute to higher levels of motivation and engagement – although further research is required in this field (Martin 2016).

In addition to supporting explicit modes of instruction, cognitive load theory also asserts that teaching domain-specific skills is more effective than teaching generic skills (Paas & Sweller 2012; Tricot & Sweller 2014). An example of a domain-specific skill might be that, when faced with a problem such as *a / b = c, solve for a*, one should multiply both sides by the denominator (Sweller 2016, p. 13). An example of a generic skill in mathematics might be general 'problem-solving' skills, such as the strategy of randomly generating moves until the correct solution is found. Cognitive load theorists suggest teaching domain-specific skills is more effective because, while general problem-solving skills are innate to humans and therefore do not need to be explicitly taught, domain-specific skills are not automatically acquired by learners without explicit teaching (Geary 2012; Tricot & Sweller 2014).

Recommendations for the classroom from cognitive load research

Cognitive load theory has produced a number of recommendations regarding instructional techniques that are directly transferable to the classroom. A selection of these are described below, to illustrate how evidence-based cognitive load research can be used by teachers to improve student outcomes.

The 'worked example effect'

A 'worked example' is a problem that has already been solved for the learner, with every step fully explained and clearly shown. The 'worked example effect' is the widely replicated finding that novice learners who are given worked examples to study perform better on subsequent tests than learners who are required to solve the equivalent problems themselves (Carroll 1994; Cooper & Sweller 1987; Sweller & Cooper 1985). The reason for this, according to cognitive load theory, is that unguided problem-solving places a heavy burden on working memory, inhibiting the ability of the learner to transfer the information into their long-term memory. The learner may effectively solve the problem, but because their working memory was overloaded they may not recognise and remember the rule that would allow them to quickly solve the same problem again in the future.

The 'expertise reversal effect'

The 'expertise reversal effect' is an important exception to the worked example effect. According to the expertise reversal effect, the heavy use of worked examples becomes less and less effective as learners' expertise increases, eventually becoming redundant[7] or even counter-productive to learning outcomes (Leslie et al. 2012; Pachman, Sweller & Kalyuga 2013; Yeung, Jin & Sweller 1998). This means that some instructional procedures such as worked examples, which assist learning for novices because they reduce cognitive load, are not effective for teaching more expert learners. While cognitive load theory supports fully guided instruction for novice learners, it also supports the gradual incorporation of more independent problem-solving tasks as learners gain expertise.

The 'redundancy effect'

Students do not learn effectively when their limited working memory is directed to unnecessary or redundant information. The 'redundancy effect' occurs when learners are presented with additional information that is not directly relevant to learning, or with the same information in multiple forms. An example is a textbook which includes both text and a diagram that needlessly repeat information, or a PowerPoint presentation in which the presenter reads the text presented on the screen. Requiring learners to process redundant information inhibits learning because it overloads working memory. Cognitive load research shows that best practice is to remove redundant information from learning material (Bobis, Sweller & Cooper 1994; Chandler & Sweller 1991; Mayer et al 1996; Torcasio & Sweller 2010). Sweller argues:

> *Most people assume that providing learners with additional information is at worst, harmless and might be beneficial. Redundancy is anything but harmless. Providing unnecessary information can be a major reason for instructional failure.*
>
> (Sweller 2016, p. 8)

The 'split attention effect'

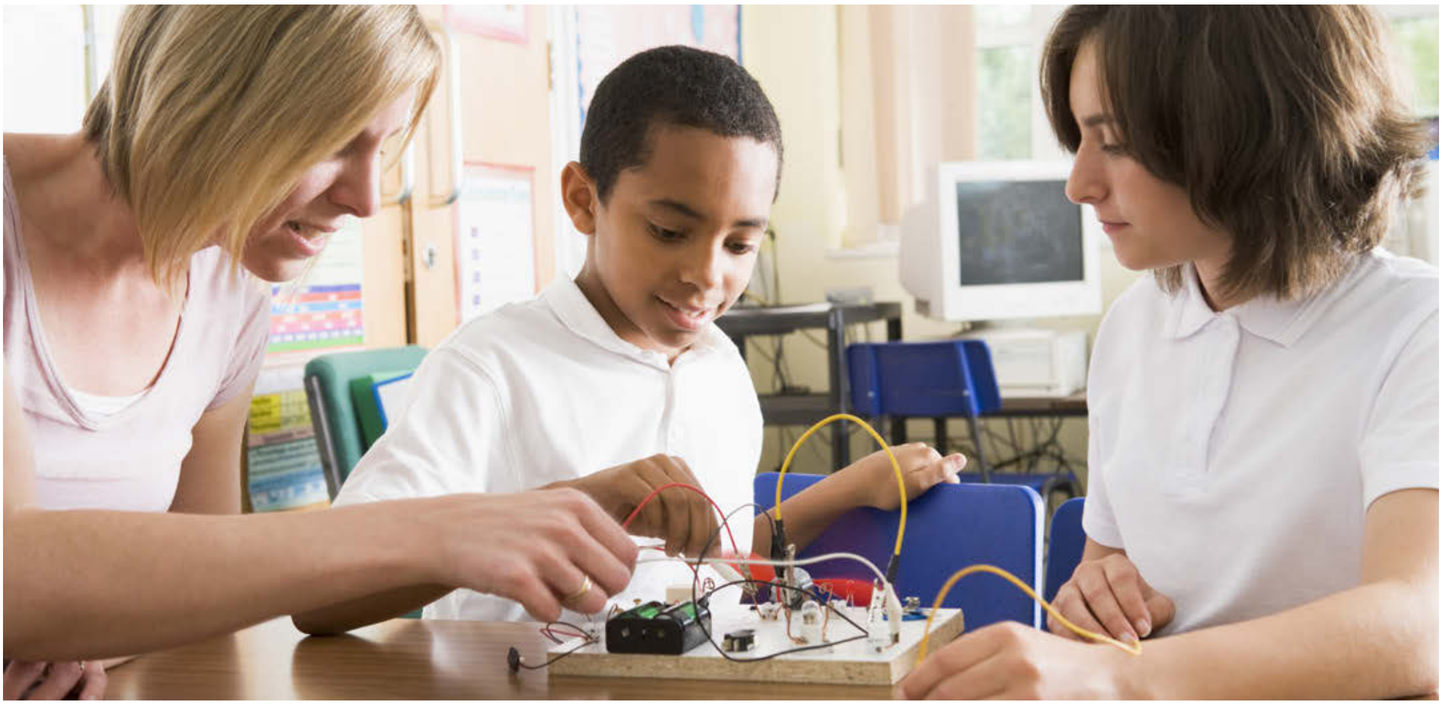
The 'split attention effect' occurs when learners are required to process two or more sources of information simultaneously in order to understand the material. This might occur, for example, when a diagram is used to explain a concept, but it cannot be understood without referring to a separate piece of explanatory text. In this instance the learner is required to hold both sources of information in their working memory at the same time and to mentally integrate the two. This places a high cognitive load on the working memory, interfering with the ability of the learner to transfer the relevant information to their long-term memory. The split-attention effect can be minimised or eliminated by physically integrating separate sources of information so that they do not have to be mentally integrated by the learner (Cerpa, Chandler & Sweller 1996; Owens & Sweller 2008; Tarmizi & Sweller 1988; Ward & Sweller 1990). Sweller, van Merrienboer & Paas argue:

> *Split attention occurs very commonly in instructional contexts. On the basis of dozens of experiments under a wide variety of conditions, the evidence suggests overwhelmingly that it has negative consequences and should be eliminated wherever possible.*
>
> (Sweller, van Merrienboer & Paas 1998, p. 281)

The 'modality effect'

The 'modality effect' is associated with the split attention effect, but offers an alternative technique to reduce cognitive load than physically integrating separate sources of information. Instead, it is also possible to decrease extraneous load on working memory by using more than one mode of communication – both visual and auditory. Evidence suggests that working memory can be subdivided into auditory and visual streams (Baddeley 1983, 2002; Baddeley & Hitch 1974), so presenting information using both auditory and visual working memory can increase working memory capacity (Penney 1989). For example, when using a diagram and text to explain a concept, the written text can be communicated in spoken form. Using both auditory and visual channels increases the capacity of working memory, and facilitates more effective learning (Jeung, Chandler & Sweller 1997; Mousavi, Low & Sweller 1995; Tindall-Ford, Chandler & Sweller 1997).

7 See the 'redundancy effect' below.



Relevance of cognitive load research in different contexts

Cognitive load theory is particularly relevant to teaching novice learners in so-called 'technical' domains such as mathematics, science and technology. A large number of RCTs demonstrate the effectiveness of the instructional approaches recommended by cognitive load theory in subjects such as maths and science (for example, Bokosmaty, Sweller & Kalyuga 2015; Carlson, Chandler & Sweller 2003; Owen & Sweller 1985; Sweller & Cooper, 1985; Zhu & Simon 1987). Far less research has been done on whether cognitive load theory is effective for teaching in less technical, or more creative subject areas – such as literature, history, art and other humanities subjects (for exceptions, see Kyun, Kalyuga & Sweller 2013; Rourke & Sweller 2009; Schworm & Renkl 2007).

The majority of studies on cognitive load do not consider how individual differences between learners might impact upon cognitive load (with the exception of differences in expertise)[8]. De Jong identifies differences in spatial ability and working memory capacity, for example, as other important considerations (2010). The literature on cognitive load theory is also silent on how other factors besides cognitive load might influence the effectiveness of learning. Roxana Moreno (2010) notes that cognitive load theory does not consider, for example, how factors such as a learner's motivation and beliefs about their own ability might influence the effectiveness of learning.

Conclusion

Cognitive load theory is a theory of how the human brain learns and stores knowledge. The theory is supported by a large number of RCTs, and has significant implications for teaching practice. Cognitive load research demonstrates that instructional methods are most effective when designed to fit within the known limits of working memory, and therefore strongly supports guided models of instruction. Cognitive load theory offers a range of evidence-backed recommendations for educational practice, especially for teaching novice learners in 'technical' subjects such as mathematics, science and technology.

8 An exception is a number of studies by van Gerven et al. (2002, 2004) that examine the impact of age on cognitive capacity.

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Centre for Education Statistics and Evaluation
GPO Box 33
Sydney NSW 2001
Australia

02 9561 1211

cese@det.nsw.edu.au

www.cese.nsw.gov.au

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