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REFLECTION ON THE FIELD

The Role of "Understanding" in Human Cognitive Architecture: A Cognitive Load Theory Perspective

Ouhao Chen[1] · **Nadine Marcus**[2] · **John Sweller**[3]

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Abstract

Within cognitive load theory, understanding is a process in which meaning is constructed by "chunking" the multiple elements that constitute high element interactivity material into a single element that is stored in long-term memory. That process does not occur for low element interactivity material to which the term "understanding" is never applied even if the material is difficult to learn due to its bulk. Based on human cognitive architecture, understanding is thus assumed to have occurred when working memory can easily process high element interactivity information as a single chunked element or a relatively small number of elements, depending on learners' expertise. This paper discusses the integration of understanding into human cognitive architecture within a cognitive load theory framework along with educational implications suggested by cognitive load theory-based instructional designs for understanding.

Keywords Cognitive Load Theory · Human cognitive architecture · Element interactivity · Learning · Understanding · Expertise and prior knowledge

Introduction

It is commonly accepted that teaching students to learn with understanding is an important goal of education (e.g., Marcus et al., 1996; Hiebert & Carpenter, 2006). Nevertheless, the role of understanding in human cognition remains contentious.

✉ Ouhao Chen
o.chen@leeds.ac.uk

[1] School of Education, Faculty of Environment and Social Sciences, University of Leeds, Leeds, UK

[2] School of Computer Science and Engineering, Faculty of Engineering, University of New South Wales, Sydney, Australia

[3] School of Education, Faculty of Arts, Design and Architecture, University of New South Wales, Sydney, Australia

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This paper will firstly discuss the various views of understanding that have been proposed followed by how the cognitive architecture used by cognitive load theory (Sweller, 2025) can incorporate the concept along with the consequent instructional procedures.

Understanding is generally defined as an active process in which meaning is constructed (Stein & Bransford, 1979; Schank & Abelson, 1977), which is personal and so varies between people (Jenkins, 1974; Johnson, 1975; Nickerson, 1985; Schank, 1982; Ziff, 1972, 1984). Marton and Säljö (1976a) suggested that there were two different levels of processing for learning: deep-level and surface-level. For deep-level processing, learners direct their attention to the intentional content of the learning materials for comprehension, such as understanding a scientific problem or a principle, whereas, for surface-level processing, learners focus more on rote-learning strategies, such as repeating or copying. Therefore, learning by understanding, is strongly associated with deep-level processing (Hounsell, 1997), whereas for learning by rote or memorisation, surface-level processing is more common.

According to some theories of the term "understanding", the key factor distinguishing understanding from memorisation/rote learning is intention (Kember, 1996). Students who intend to understand use deep-level processing, attempting to understand the inherent meaning of learning materials, leading to learning with understanding, whereas students who do not have an intention to understand the learning materials tend to use surface-level processing, with little or no understanding as a learning outcome, leading to memorisation/rote learning. On this view, memorisation/rote learning and understanding are separate concepts based on students' intent. However, it has been suggested that understanding and memorisation/rote learning are not distinct entities when learning but are intertwined, collaborating activities (Marton & Booth, 2013). Memorisation/rote learning may be a step towards the process of understanding.

One approach suggests that students work through information section-by-section to gain understanding and then memorise what they have learned (Kember & Gow, 1990). An alternative suggestion reverses this process. Initially, students may intend to memorise the learning content without understanding. As they progress and increase their knowledge, where "knowledge" is defined as information stored in long-term memory, students may see the value of learning with understanding. They may change their intention to learning with understanding as they have seen the value of understanding, but they may still have the need for some memorisation/rote learning. Therefore, according to these suggestions, the order of memorisation/rote learning and understanding is not linear but changeable and dynamic.

However, "understanding" may not always be the intended learning outcome, as it is based on the content being taught. From a cognitive load theory perspective, instructional effects are most relevant when learners must understand complex materials, especially when they have low prior knowledge. Conversely, for low-complexity content, the issue of understanding may be irrelevant, so many cognitive load theory-based instructional effects may be less critical to understanding, as will be discussed in more detail below. In this paper we assume understanding increases efficiency but that is not the only way of increasing efficiency. There are

other ways of increasing efficiency that do not require understanding. Nevertheless, we doubt that understanding ever occurs without increasing familiarity, automation, and memorisation.

The Role of Understanding in Human Cognitive Architecture

While learning with understanding is a common educational goal, it is a goal that is rarely associated with our knowledge of human cognitive architecture. We will outline that architecture (Sweller, 2025; Sweller et al., 2019) and indicate how understanding can be incorporated into it.

Biologically Primary and Secondary Information

Information can be categorised as either biologically primary or secondary (Geary, 2008, 2024; Geary & Berch, 2016). Over many generations we have evolved to acquire primary information easily and effortlessly. Learning to listen to and speak our native language provides an example. Most people will acquire that very complex skill automatically without instruction. While instruction may facilitate higher levels of a primary skill, if instruction is completely absent, we can still acquire competency solely by interacting with other people in a functioning society. Accordingly, understanding a native language does not require instruction. We have evolved to understand a native language as a biologically primary skill.

In contrast to biologically primary information, biologically secondary information must be taught in order to be acquired. For example, most people need to be taught to read and write. While writing was invented several thousand years ago, the vast majority of all populations remained illiterate until mass education became common about 150 years ago. Unlike listening and speaking, instruction is normally required for the acquisition of reading and writing. Schools were developed in order to instruct students in the biologically secondary knowledge and skills that societies considered essential and that were not developed automatically like primary skills. Despite its immense complexity, understanding one's native language as primary knowledge does not require instruction. Understanding mathematics or the causes of World War 1 as secondary knowledge does require instruction.

Knowledge Elements and Prior Knowledge for Understanding

The role of knowledge elements and prior knowledge have been well documented in text comprehension research (Kintsch, 1994, 1998). When knowledgeable learners learn to understand text, the known elements of the text should activate learners' knowledge net stored in long-term memory (retrieval) for understanding, particularly compared to novice learners. Knowledgeable learners thus show more links between the text and prior knowledge compared to novices, helping them make inferences required for understanding.

Variations in the Complexity of Biologically Secondary Knowledge As well as dividing information into biologically primary and secondary categories, secondary information also can be categorised according to element interactivity with cognitive load theory using element interactivity to determine complexity (Chen et al., 2023; Sweller, 1994, 2010). Element interactivity is determined by the extent to which multiple, biologically secondary elements must be considered simultaneously in order to be understood. For example, to understand the following problem and its solution, *(a + b)/c = d*, *solve for a*, each of the elements of the problem, along with the rules of algebra and the application of those rules to the problem must be considered simultaneously because all these multiple elements interact for understanding. Accordingly, the element interactivity of the above problem is high. The term "understanding" can be applied to this high element interactivity problem and its solution.

In contrast, consider learning the nouns of a second language. That task is very difficult but low in element interactivity. Each word can be learned independently of every other word. When learning that "le chat" is the French translation of "the cat", we do not need to consider that "le chien" is the translation of "the dog". Each noun can be learned independently of every other noun. That independence has a consequence for use of the term "understanding". If a person has not learned or has forgotten that the French translation of "the cat" is "le chat", we would not state that they do not "understand" the translation, as the term "understanding" only is applied to high, not low element interactivity information.

It needs to be emphasised that element interactivity and task difficulty are independent concepts. A task can be very low in element interactivity but very difficult if there are many low element interactivity components that must be learned. As indicated above, learning the nouns of a second language is a very difficult task that may need to be spread over several years despite each component being low in element interactivity. Learning to solve elementary algebra problems may be difficult but the difficulty is not due to the large number of components. Instead, because the components interact, they and the relations between them usually need to be learned simultaneously resulting in a high element interactivity task.

In the above examples, element interactivity is described solely with reference to the characteristics of the information. Some information can be categorised as being high in element interactivity while other information is low in element interactivity. While there are psychological consequences of the differences between high and low element interactivity information with, for example, high element interactivity information imposing a higher working memory load than low element interactivity information, the definition of element interactivity does not depend on those psychological consequences. There is a critical factor that determines the effect of element interactivity: the knowledge held in long-term memory. This factor is critical to the effect of element interactivity and accordingly, critical to understanding.

Expertise moderates the Level of Element Interactivity for Understanding When novices are asked to solve the above algebra problem, *solve (a + b)/c = d for a*, they need to simultaneously process the 7 interactive elements that constitute the equation, along with the relevant rules of algebra needed to solve the problem. Otherwise,

if they process the many elements individually and separately, they will not be able to understand the equation or the problem as a whole. In contrast, someone who is very experienced in solving such equations can just treat the integrated knowledge as a single element reducing the level of element interactivity, called "chunking" by Miller (1956). Accordingly, information that consists of multiple, interacting elements for a novice may be treated as a single element or chunk of information by an expert. The mechanics and consequences of this process for understanding are discussed below.

The Acquisition of Information

There are two ways we can acquire new knowledge, obtaining information from others or engaging in problem solving, with both being biologically primary and so unteachable. First, novel information can be acquired via problem solving. The most common problem solving strategy is means-ends analysis (Newell & Simon, 1972) which requires problem solvers to consider their current and goal problem states, and find a problem solving operator that will reduce the differences between the two states. That procedure can be repeated until the goal is reached. The procedure is complex, but we find it simple because it is biologically primary and so unteachable because we all acquire it automatically. Obtaining information through problem solving can be lengthy and difficult not because we find the strategy difficult but because the materials such as, for example, mathematical expressions, may be unfamiliar. Nevertheless, problem solving is essential because frequently the alternative method of obtaining novel information is not available. That alternative method is by transmission from other people.

We have evolved to obtain information from other people as a biologically primary skill and are the only species capable of obtaining large amounts of information from other members of the species. This biologically primary technique for obtaining biologically secondary information is capable of quickly and efficiently obtaining large amounts of information that otherwise might take years to acquire through problem solving.

Processing Novel Information

Irrespective how it is obtained, novel, biologically secondary information must first be processed by a limited capacity (Baddeley, 1992; Baddeley et al., 2021; Miller, 1956), limited duration (Peterson & Peterson, 1959) working memory. When dealing with novel, secondary information, working memory is unable to hold more than about 7 items of information and process more than about 3–4 items of information where processing means manipulating the items (combining, comparing, considering) in some manner.

The consequences for understanding novel, high element interactivity, secondary information are clear. We have difficulty understanding novel, high element interactivity information that requires us to mentally manipulate more than about 3–4 elements of that information simultaneously but can understand and process low element interactivity information which imposes a low working memory

load. Currently, there is no evidence that the same working memory capacity and duration restrictions also apply to the initial acquisition of biologically primary information.

Storing Information

Once information has been processed in working memory, it can be transferred to long-term memory for later use (Shipstead et al., 2016). Unlike working memory, long-term memory has no known capacity or duration limits. It can hold enormous quantities of integrated knowledge. A large part of that knowledge includes previously, difficult to understand, high element interactivity information that has been transformed by chunking, into easily understood, low element interactivity chunks of information. The limited capacity of working memory when dealing with novel, high element interactivity information is eliminated by this chunking process in which not only is information stored in long-term memory, but simultaneously, multiple smaller units are combined into larger units (Miller, 1956; Thalmann et al., 2019) that can be readily processed by working memory.

It needs to be noted that, as indicated above, the process of understanding does not apply to information that is initially low in element interactivity and so never needs to be chunked to be understood. We may or may not have learned that "le chat" is French for "the cat", but we would not normally apply the term "understanding" to that knowledge. In contrast, learning French grammar does require understanding because it is high in element interactivity. Nevertheless, once stored in long-term memory, learned grammar reduces from high to low element interactivity.

Current perspectives on working memory capacity are related to attention with working memory capacity being the number of items a person can pay attention to at any one point in time (Cowan, 2001; Cowan et al., 2005). Individual differences in working memory capacity may be partly explained by differences in allocating attention to maintain important information (Engle, 2002; Engle & Kane, 2004).

Using Stored Information to Govern Action

As indicated above, for an expert in elementary algebra, the many elements that constitute the problem "*(a + b)/c = d, solve for a"* and its solution constitute a single element that no longer places a burden on working memory due to the individual interacting elements being chunked into a single unit. When faced with that problem, rather than the difficult task of having to manipulate multiple, interacting elements in working memory, an expert merely can transfer a single element from long-term to working memory to solve the problem. In contrast to novel information processed in working memory, retrieving stored knowledge from long-term memory to working memory is not influenced by working memory limitations (Ericsson & Kintsch, 1995). An expert "understands" the problem and its solution. Understanding requires the consolidation of biologically secondary, high element interactivity information into fewer elements or chunks held in long-term memory which are transferrable to working memory to govern action appropriate to the extant environment. In this manner, our cognitive architecture allows us to function in a manner we otherwise could not dream of.

Summarising, the concept of "understanding" fits easily and automatically into the integrated cognitive architecture that underlies cognitive load theory. Understanding applies to the acquisition of high element interactivity information. Once it has been stored in long-term memory, understanding is achieved, and it no longer acts as high element interactivity knowledge and so can be transferred back to working memory as a single element to govern appropriate action. Understanding means that due to the retrieval of information stored in long-term memory, working memory can now easily process previously high-element-interactivity information as a single element or as a relatively small number of elements. It improves performance and reduces cognitive load.

The above discussed relations between understanding and learning align with the generative learning framework formulated by Fiorella and Mayer (2015, 2016). The framework suggests that learners select information registered by sensors and then organise selected information into a coherent mental structure in working memory, before integrating the new mental structure with knowledge stored in long-term memory, which aligns with the cognitive load theory view of information processing for understanding.

Instructional Designs for Understanding – Hypotheses, Instructional Effects and Educational Implications

This cognitive architecture provides a base for Cognitive Load Theory. Since the theory is an instructional theory, that rests on the above cognitive architecture, the theory provides a base for learning with understanding. Any instructional advantages accrued by use of the theory should be associated with increased understanding.

There are many cognitive load theory effects that have been generated by the theory. Human cognitive architecture is used as a base to generate hypotheses that when successfully tested, lead to a variety of instructional effects. Each effect is based on multiple, randomised controlled trials demonstrating that learning is facilitated by using an instructional design generated from the theory. The generation of such effects has a dual purpose. First, it provides a new instructional procedure which is the main purpose of the theory. Second, the theory's ability to generate novel experimental results provides a degree of validation for the theory. Reviews of the many instructional effects generated by the theory may be found elsewhere (Sweller et al., 2019). The vast majority of the experiments testing for the effects require students to understand complex, high element interactivity information allowing them to solve problems in the many educationally relevant domains.

The role of understanding is critical to all the empirically validated cognitive load theory effects that are due to reductions of extraneous cognitive load from the redesign of instructional content, rather than optimisation of intrinsic cognitive load. Cognitive load effects due to a reduction in extraneous cognitive load are demonstrated when an instructional design reduces working memory load. In turn, learning itself reduces element interactivity by converting high element interactivity information into a single element or chunk held in long-term memory. When that single element is transferred back to working memory to generate action appropriate to the environment, understanding has occurred.

As an example, using worked examples to teach novices complex information can reduce extraneous cognitive load by reducing the level of element interactivity when compared to solving equivalent problems. When we use worked examples to direct novices to a few new and challenging steps with minimised cognitive load, they can use more of their working memory resources to deal with the high element interactive learning materials themselves for understanding and learning.

However, if we ask novices to solve problems without relevant knowledge, this will increase the level of extraneous cognitive load by increasing the level of element interactivity involved when randomly generating, searching and combining potential steps during trial-and-error, requiring novices to use their limited working memory resources to deal with an extraneous cognitive load that is irrelevant to learning and understanding the materials, reducing understanding. A worked example is easier to understand than a problem because it does not involve activities such as trial-and-error step searching that are extraneous to learning. Once the high element interactive information is learned it can be stored in long-term memory as a single chunk or element thus allowing easy transfer to working memory to govern appropriate action, and understanding can be further facilitated.

The isolated elements effect (Pollock et al., 2002) also provides a very clear example of the role of element interactivity in understanding. Novice learners may find very high element interactivity information impossible to understand because they are unable to manipulate the multiple elements simultaneously in working memory. Initially, they may only be able to rote learn the various elements without being able to combine them into the interactive whole. Once rote learned, it may be possible to combine the various elements into an interactive form before storing the fully interactive form in long-term memory. The fully formed interactive version can then be readily transferred to working memory for relevant action. Pollock et al. (2002) found that learners asked to initially learn the fully understandable, interacting version of very high element interactivity information learned less and were less able to use the information than learners who were first asked to rote learn individual elements before they were combined into their final, interactive form. Thus paradoxically, initial rote learning without understanding facilitated subsequent understanding of very high element interactivity information, demonstrating the isolated elements effect.

It follows that implementing cognitive load theory-informed instructional strategies may require consideration of how to apply worked examples to teach and how to engage novices to learn, first by rote memorisation followed by learning for understanding via the isolated elements effect. Since understanding may not be the intended learning objective because it only is needed for materials high in element interactivity, this procedure only is relevant under high rather than low complexity learning conditions.

Theoretical Contributions

In contrast to other theoretical frameworks for understanding, cognitive load theory defines understanding based on the central concept of element interactivity and human cognitive architecture. The theory assumes that to achieve understanding

of high element interactivity information, working memory must be able to process that information for storage in long-term memory. Once stored as chunks, the information is reduced in element interactivity allowing ready retrieval for appropriate action.

However, understanding and the ability to transfer are different concepts. We can use transfer to provide evidence of understanding, but a failure to transfer does not mean a particular level of understanding has not been attained. For example, someone may fully understand how to solve a problem such as $a + b = c$, *solve for a*, but fail to recognise that it is one of the moves required to solve $a/b + c = d$, *solve for a*. The failure to solve the second transfer problem does not indicate a failure to understand the solution to the first problem. Solution of the second problem will require additional information stored in long-term memory. This relation between understanding and transfer requires additional experimentation by testing whether additional knowledge allows additional transfer.

Conclusions

"Understanding" is not a separate, independent component of human cognitive architecture, but is rather integrated throughout our cognitive system. It flows automatically and naturally from the manner in which the components of the system are organised, with the chunking of high element interactive materials into a single element supporting the construction of meaning. Accordingly, understanding can be taught and acquired by considering these components. Since cognitive load theory rests on a particular version of human cognitive architecture, if the theory is valid, the best way of "teaching for understanding" is by following the precepts of the theory.

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Declarations

Ethical Approval Not applicable.

Conflict of interest No.

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