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AN INTERVIEW WITH JOHN SWELLER

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An introduction

Emeritus Professor John Sweller is presently a professor of Education at the University of New South Wales, Sydney, Australia. After receiving the Bachelor's degree in 1969 at the University of Adelaide, he completed a PhD degree at the same university in 1972.The name of John Sweller is associated with the cognitive load theory, an instructional theory based on our knowledge of human cognitive architecture.

The theory is a contributor to both research and debate on issues associated with human cognition, its links to evolution by natural selection, and the instructional design consequences that follow.

Sweller initiated work on the theory in the early 1980's. Subsequently, "ownership" of the theory shifted to his research group at UNSW and then to a large group of international researchers. The theory is now a contributor to both research and debate on issues associated with human cognitive architecture, its links to evolution by natural selection, and the instructional design consequences that follow. It is one of the few theories to have generated a large range of novel instructional designs from our knowledge of human cognitive architecture. The following instructional design effects have flowed from cognitive load theory: goal-free, worked example, split-attention, redundancy, modality, element interactivity, isolated-interacting elements, imagination, expertise reversal, completion, variable examples, guidance fading, transient information, collective working memory and random move generation effects. These effects have been studied by many groups of researchers from around the globe.

Sweller has authored over 150 book chapters and academic publications, mainly reporting research on cognitive factors in instructional design, with specific emphases on the instructional implications of working memory limitations and their consequences for instructional procedures. Sweller has also published several well-known books on the cognitive load theory, including *Efficiency in learning: Evidence-based guidelines to manage cognitive load* (with Clark and Nguyen) and *Cognitive load theory* (with Ayres and Kalyuga), published in 2011.

Why don't we begin with a brief biography?

I was born in Poland in 1946 and migrated to Australia with my parents in 1948. My university education consisted of a Bachelor's degree in psychology followed by a PhD that included research into problem solving. Most of my career has been spent in the School of Education at the University of New South Wales where I lectured in Educational Psychology and carried out research into cognitive processes and instructional design.

Cognitive load theory

How did the idea of Cognitive Load Theory (CLT) develop?

Slowly, over many years. The theory is continually being developed as new ideas and new data arrive. The theory began when I noticed while running an experiment that problem solvers could successfully solve a problem but have no idea how they had done so. In other words, they seemed to learn little from the experience. I realized that searching for a problem solution and learning critical aspects of a problem are two quite different processes. Because working memory capacity and duration are very limited, we can successfully search for a problem solution but have insufficient working memory resources to learn what moves were required and why they were required. In education, a failure to learn, where learning means storing information in long-term memory, renders the instructional procedure largely useless.

In CLT, you use a particular jargon, for example, extraneous, intrinsic and germane load. Could you explain the meaning for us? How did these concepts develop?

Cognitive load theory consists of human cognitive architecture (e.g. working memory and long-term memory), categories of cognitive load (extraneous, intrinsic and germane cognitive load) and the cognitive load effects that describe experimental effects (e.g. worked example, split-attention, modality, redundancy effects – there are many more) that lead to instructional principles. The various parts of the theory were slowly developed over many years. The theory led to hypotheses and experiments. When data from experiments contradicted the theory, the theory was modified, usually by being expanded.

The expansion that resulted in the concept of intrinsic cognitive load provides an example. Initially, when we referred to cognitive load, we were discussing what is now known as extraneous cognitive load. We made no distinctions between categories of cognitive load. But then we discovered that the cognitive load effects that we could obtain with some material just did not show up with other material. Why? Eventually, we realised that the information that did not result in effects showing up was easy to process. It did not impose a heavy working memory load because of its intrinsic nature. We only obtained cognitive load effects using complex, difficult to understand information that imposed a heavy, intrinsic cognitive load. If instruction also imposed a heavy extraneous cognitive load, the system collapsed and learning did not occur. For easy to understand information, it did not matter how the information was presented. Even with an increase of extraneous cognitive load, working memory was not overloaded. For example, learning that Fe is the symbol for iron does not tax working memory and so an inappropriate instructional procedure may not matter a great deal. Learning how to balance an equation may impose a heavy working memory load (intrinsic cognitive load) and so how it is taught may be critical because an inappropriate instructional procedure will impose an extraneous cognitive load.

What forms of cognitive load are useful?

Working memory resources should be devoted to dealing with intrinsic cognitive load, not extraneous cognitive load. If extraneous cognitive load is reduced, more resources can be devoted to intrinsic information. Resources devoted to intrinsic information are germane which is positive.

As a scholar of human cognitive architecture, could you explain the function of long-term memory?

All learning, no matter what its nature, results in a change in long-term memory. If nothing has changed in long-term memory during instruction, nothing has been learned. Once information is stored in long-term memory, we become different people. We can do things we could not dream of doing prior to learning. Information that overloaded working memory prior to it being stored in long-term memory, can be processed easily, quickly and smoothly after it has been stored in long-term memory. Accordingly, the function of instruction is to increase usable information in long-term memory.

So, is there a reason why transfer is so difficult in problem solving?

Transfer relies on us being able to recognize that previously learned material can be applied in a new situation. First, we must obtain cues indicating that it is appropriate to use particular knowledge in the new context. If those cues are missing, we cannot possibly recognize that the new context is related or perhaps functionally equivalent to the old context. Second, even if appropriate cues are present, we have a cognitive load problem. We simultaneously must hold the old context in working memory, the solution to the problem in the old context, search for relations between the old and new contexts, and work out how to apply the previous problem solution in the new, transfer context. All of these processes must be carried out in a working memory that can only process two or three new elements simultaneously. The result is that unless learners are explicitly provided with relations between problems, they are most unlikely to discover those relations by themselves unless the relations are obvious.

What are the characteristics of human cognition that allow us to deal with some material more easily than other material?

We are discussing intrinsic cognitive load here. New chemistry students may have difficulty learning the symbols of the periodic table but each symbol can be learned in isolation. The symbol for iron can be learned independently of the symbol for carbon. Element interactivity is low where an element is anything that needs to be learned (as distinct from a chemical element). When element interactivity is low, intrinsic cognitive load is low. Learning an individual element does not place a heavy load on working memory. In contrast, chemistry students may have difficulty learning to balance chemical equations but the difficulty is very different to the difficulty they face in learning the symbols of the periodic table. Learning to balance chemical equations requires learners to simultaneously manipulate several learning elements simultaneously in working memory. Any change in one part of an equation has implications for several other parts and all must be considered simultaneously. The learning elements interact and cannot be considered in isolation. Because they interact, each learning element must be considered simultaneously with several other elements. Working memory load is high due to high element interactivity and so intrinsic cognitive load is high.

There is another relevant issue associated with human cognitive architecture and ease of learning that cognitive load theory has begun to emphasize in recent years. According to Geary (2008), knowledge can be divided into biologically primary knowledge that we have evolved to acquire and biologically secondary knowledge that we have not specifically evolved to acquire. Primary knowledge can be acquired easily and unconsciously without specific instruction. Learning to listen to and speak a native language provides an example. We have evolved to acquire a native language. Secondary knowledge is much more difficult to acquire and requires explicit instruction. Chemistry provides an example. We can learn Chemistry but we have not evolved to learn Chemistry. It must be learned consciously and taught explicitly.

"If nothing has changed in long-term memory, nothing has been learned." (Sweller, Ayres & Kalyuga, 2011, p. 24) Which instructional procedures can facilitate changes in long-term memory? Does motivation play a role here?

Cognitive load theory has been used to devise a list of effective instructional procedures that facilitate change in long-term memory. Each has been demonstrated to be effective using randomised, controlled experiments. Each reduces extraneous cognitive load.

Motivation is critical but is usually considered to be independent of cognitive load factors. Any instructional technique can be manipulated to increase or decrease motivation independently of whether cognitive load is or is not altered.

According to Johnstone's Ten Educational Commandments (Johnstone, 1997, p. 265), "If learning is to be meaningful it has to link on to existing knowledge". Why must meaningful knowledge be linked to existing knowledge and why do learners frequently engage in rote-learning?

Knowledge can be stored in long-term memory as rote-learned, isolated facts, but such knowledge tends to have a limited utility. All knowledge, including facts, are best stored as integrated, connected knowledge elements known as "schemas". Such meaningful knowledge is harder to acquire than rote-learned knowledge because it imposes a heavy, intrinsic cognitive load. It is easier for learners to treat a series of knowledge elements as unrelated because that reduces working memory load during learning. Element interactivity is reduced because when rote-learned, links between knowledge elements are ignored. Of course, while acquiring knowledge in this form can be easier, it is far less useful. Useful knowledge is more likely to consist of complexes of interrelated knowledge elements (schemas) that derive meaning from their interrelations.

Many people think that multimedia is good for learning. In CLT, you have found such effects as the split-attention effect. What do you think about the potential of multimedia for learning?

There are several cognitive load theory effects concerned with multi-media learning. The split-attention effect says that when we are faced with two or more sources of information such as a diagram and text that refer to each other but where each is unintelligible without the other, then relevant sections of the text should be placed at appropriate locations on the diagram so that learners do not need to split their attention between the two and search for referents. Physically integrating the two sources of information reduces extraneous cognitive load compared to a split-attention presentation.

As an alternative, if the text is short and easily held in working memory, rather than physically integrating it with the diagram, it can be presented in spoken form. Dual modality presentation is superior to single modality presentation resulting in the modality effect.

The relation between the two sources of information is critical. They must be unintelligible in isolation. If both sources are intelligible in isolation because, for example, the text merely re-describes the diagram, they should not be physically integrated or partly presented in oral form. Rather, one form of presentation, usually the text, should be eliminated. Improved performance after eliminating a redundant source of information provides an example of the redundancy effect.

Problem Solving

Problem Solving is one of the main areas of your research. When do you think problem solving is productive and when is it not productive?

Problem solving is productive when we want to find the solution to a problem. The only time that happens within an educational context is during a test. Somehow, during the history of educational thought, we decided that problem solving was also a good way of learning. It is a terrible way of learning. We decided that problem solving was a good way of learning without any evidence and without even attempting to obtain evidence from randomized controlled experiments. Problem solving is a poor way of learning because it imposes a large, extraneous cognitive load. To solve a problem we need to simultaneously consider the current problem state, the goal state, differences between the two states, and problem solving operators that can reduce those differences. None of these working memory resource sapping activities has more than a marginal relation to learning to recognize problem states and the best moves associated with those states. Instead of having learners solve problems, show them how to solve problems. The worked example effect occurs when students who study worked examples perform better on problem solving tests than students who solve problems. The effect has been demonstrated on dozens of occasions.

When novices study worked examples, their problem-solving skills improve more than by merely trying to solve the equivalent problems by themselves. (Renkl, 2005) How should worked examples be structured?

The most important consideration is the elimination of split-attention. Worked examples that incorporate split-attention need to be modified so that multiple sources of information are physically integrated. Recent research is increasingly indicating that the elimination of redundancy also is important.

According to Moreno, "there is strong evidence that worked examples don't always work" (Moreno, 2006, p. 177) When is problem solving superior to studying worked examples? (Kalyuga, Chandler, Tuovinen & Sweller, 2001)

Badly structured worked examples, as indicated in the previous answer, certainly are ineffective. But there is another set of circumstances in which they are ineffective. For novices, properly structured worked examples seem always to be effective. As levels of expertise increase, the advantage of worked examples decreases, disappears and finally, reverses with problem solving being superior to worked examples. These relations provide an example of the expertise reversal effect. Initially, we need worked examples to show us how to solve particular classes of problems because being shown how to solve problems reduces working memory load compared to solving problems. With increasing expertise, being shown how to solve a class of problems is redundant and so no longer is necessary because redundant information itself increases cognitive load. With increasing expertise, we merely need to practice solving problems rather than being shown how to solve them.

"The most widely used definition of creativity is the generation of products or problem solutions that are both novel and useful" (James & Taylor, 2010, p. 33) Specific knowledge is always important? What is the role of motivation?

Without motivation, we will create little or nothing. Indeed, without motivation we are unlikely to learn or to solve problems.

CLT and learning

Your advice to instructors is to minimize the irrelevant cognitive load. (Clark, Nguyen & Sweller, 2006) What does this mean in practice?

It means putting into practice the cognitive load effects that have been demonstrated. Provide learners with explicit instruction rather than have them search for information. Use properly structured worked examples that eliminate split-attention and redundancy. As levels of expertise increase, reduce those worked examples and replace them with problems to solve. Take care to ensure that when using educational technology you do not replace permanent information such as written text or static graphics with transient information such as spoken text or animations that increase cognitive load due to the transient information effect. There are many other considerations based on cognitive load theory but these are major ones.

How does the human cognitive system deal with complexity?

Ingeniously! It builds ever more complex information structures in long-term memory and then treats those structures, that can be massively complex, as a single, simple element in working memory when knowledge is needed to provide actions.

Constructivism has had a major influence in science and mathematics education. "The most conspicuous psychological influence on curriculum thinking in science since 1980 has been the constructivist view of learning" (Fensham, 1992, p. 801) Why does minimal guidance during instruction not always work?

Constructivism as a philosophical/psychological theory says that we all must construct our knowledge of the world. It is unobjectionable. Constructivism as a teaching procedure says we need to teach learners how to construct knowledge by having them discover it themselves rather than explicitly teaching them. I find it non-sensical. It was not introduced because the empirical evidence indicated it needed to be introduced but rather, as a dogma. Currently, it seems to be going the way of most empirically unsupported dogmas.

How much and what type of guidance is optimal for learning from instruction?

For novices, detailed explicit instruction including lots of worked examples. As levels of knowledge in a domain increase, levels of explicit instruction can decrease. Once learners are able to easily obtain information such as problem solutions themselves, very little information needs to be provided.

There are three aspects of representation in the physical sciences: macro and tangible; molecular and invisible; symbolic and mathematical. (Johnstone, 2010) An expert chemist can juggle all three levels, but what about a student? Any advice from the CLT?

Most students, certainly novices, are likely to find juggling all three levels imposes an overwhelming working memory load. The problem can be overcome by teaching each level in isolation prior to bringing the levels together. This procedure follows from the isolated-interacting elements effect.

You demonstrated that split attention is negative in all instruction. (Sweller et al., 1990) How can the split attention be eliminate in a chemistry textbook?

Pick up any chemistry textbook and you will find lots of text, lots of equations and lots of pictures and diagrams. For novices (and the books are written for novices) to understand an equation or a diagram, they need to hold it in working memory while reading the text. That is easy for an expert but likely to be impossible for a novice. Physically integrating them reduces working memory load. It requires a lot of thought, work and effort on the part of writers but can have dramatic effects on learning outcomes.

Now a personal question: what have been the most significant events in your own teaching life?

Probably the realization that treating teaching as an empirical and theoretical science rather than as a craft can have enormous benefits.

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