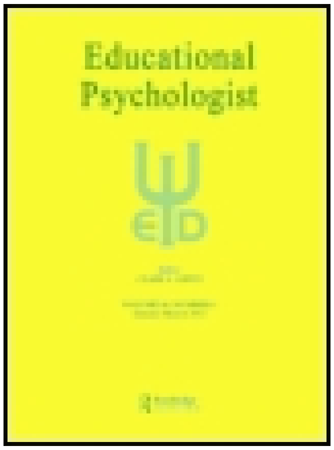

Educational Psychologist
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/hedp20

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Published online: 08 Jun 2010.

EDUCATIONAL PSYCHOLOGIST, *38*(1), 1–4

Cognitive Load Theory and Instructional Design: Recent Developments

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Cognitive load theory (CLT) originated in the 1980s and underwent substantial development and expansion in the 1990s by researchers from around the globe. As the articles in this special issue demonstrate, it is a major theory providing a framework for investigations into cognitive processes and instructional design. By simultaneously considering the structure of information and the cognitive architecture that allows learners to process that information, cognitive load theorists have been able to generate a unique variety of new and sometimes counterintuitive instructional designs and procedures.

The genesis of this special issue emerged from an international symposium on CLT that was organized at the 2001 Biannual Conference of the European Association for Research on Learning and Instruction, Fribourg, Switzerland. Most of the articles that follow are based on contributions to that symposium and discuss the most recent work carried out within the cognitive load framework. Before summarizing those articles, we provide a brief outline of CLT.

Although the information that learners must process varies on many dimensions, the extent to which relevant elements interact is a critical feature. Information varies on a continuum from low to high in element interactivity. Each element of low-element interactivity material can be understood and learned individually without consideration of any other elements. Learning what the usual 12 function keys effect in a photo-editing program provides an example. Element interactivity is low because each item can be understood and learned without reference to any other items. In contrast, learning how to edit a photo on a computer provides an example of high-element interactivity. Changing the color tones, darkness, and contrast of the picture cannot be considered independently because they interact. The elements of high-element interactivity material can be learned individually, but they cannot be understood until all of the elements and their interactions are processed simultaneously. As a consequence, high-element interactivity material is difficult to understand.

Element interactivity is the driver of our first category of cognitive load. That category is called *intrinsic cognitive load* because demands on working memory capacity imposed by element interactivity are intrinsic to the material being learned. Different materials differ in their levels of element interactivity and thus intrinsic cognitive load, and they cannot be altered by instructional manipulations; only a simpler learning task that omits some interacting elements can be chosen to reduce this type of load. The omission of essential, interacting elements will compromise sophisticated understanding but may be unavoidable with very complex, high-element interactivity tasks. Subsequent additions of omitted elements will permit understanding to occur. Simultaneous processing of all essential elements must occur eventually despite the high-intrinsic cognitive load because it is only then that understanding commences.

One may argue that this aspect of the structure of information has driven the evolution of human cognitive architecture. An architecture is required that can handle high-element interactivity material. Human cognitive architecture met this requirement by its combination of working and long-term

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memory. *Working memory,* in which all conscious cognitive processing occurs, can handle only a very limited number—possibly no more than two or three—of novel interacting elements. This number is far below the number of interacting elements that occurs in most substantive areas of human intellectual activity. Alone, working memory would only permit relatively trivial human cognitive activities. *Long-term memory* provides humans with the ability to vastly expand this processing ability. This memory store can contain vast numbers of *schemas*—cognitive constructs that incorporate multiple elements of information into a single element with a specific function.

Schemas can be brought from long-term to working memory. Whereas working memory might, for example, only deal with one element (e.g., a cognitive load that can be handled easily), that element may consist of a large number of lower level, interacting elements. Those interacting elements may far exceed working memory capacity if each element had to be processed. Their incorporation in a schema means that only one element must be processed. If readers of this article are given the problem of reversing the letters of the last word of the last sentence mentally, most will be able to do so. A schema is available for this written word along with lower level schemas for the individual letters and further schemas for the squiggles that make up the letters. This complex set of interacting elements can be manipulated in working memory because of schemas held in long-term memory. The automation of those schemas so that they can be processed unconsciously further reduces the load on working memory. It is by this process that human cognitive architecture handles complex material that appears to exceed the capacity of working memory.

CLT is concerned with the instructional implications of this interaction between information structures and cognitive architecture. As well as element interactivity, the manner in which information is presented to learners and the learning activities required of learners can also impose a cognitive load. When that load is unnecessary and so interferes with schema acquisition and automation, it is referred to as an *extraneous* or *ineffective cognitive load.* Extraneous cognitive load is a second category of cognitive load. Many conventional instructional procedures impose extraneous cognitive load because most instructional procedures were developed without any consideration or knowledge of the structure of information or cognitive architecture. For example, any instructional procedure that requires learners to engage in either a search for a problem solution or a search for referents in an explanation (i.e., when Part A of an explanation refers to Part B without clearly indicating where Part B is to be found) is likely to impose a heavy extraneous cognitive load because working memory resources must be used for activities that are irrelevant to schema acquisition and automation. The articles in this special issue are concerned with this second category of cognitive load, extraneous cognitive load, and, indeed, cognitive load theorists spend much of their time devising alternative instructional designs and procedures that reduce extraneous cognitive load compared to conventionally used procedures.

Extraneous cognitive load is primarily important when intrinsic cognitive load is high because the two forms of cognitive load are additive. If intrinsic cognitive load is low, levels of extraneous cognitive load may be less important because total cognitive load may not exceed working memory capacity. As a consequence, instructional designs intended to reduce cognitive load are primarily effective when element interactivity is high. When element interactivity is low, designs intended to reduce the load on working memory have little or no effect.

The last form of cognitive load is *germane* or *effective cognitive load.* Like extraneous cognitive load and unlike intrinsic cognitive load, germane cognitive load is influenced by the instructional designer. The manner in which information is presented to learners and the learning activities required of learners are factors relevant to levels of germane cognitive load. Whereas extraneous cognitive load interferes with learning, germane cognitive load enhances learning. Instead of working memory resources being used to engage in search, for example, as occurs when dealing with extraneous cognitive load, germane cognitive load results in those resources being devoted to schema acquisition and automation. Note that increases in effort or motivation can increase the cognitive resources devoted to a task. If relevant to schema acquisition and automation, such an increase also constitutes an increase in germane cognitive load.

Intrinsic, extraneous, and germane cognitive loads are additive in that, together, the total load cannot exceed the working memory resources available if learning is to occur. The relations between the three forms of cognitive load are asymmetric. Intrinsic cognitive load provides a base load that is irreducible other than by constructing additional schemas and automating previously acquired schemas. Any available working memory capacity remaining after resources have been allocated to deal with intrinsic cognitive load can be allocated to deal with extraneous and germane load. These can work in tandem in that, for example, a reduction in extraneous cognitive load by using a more effective instructional design can free capacity for an increase in germane cognitive load. If learning is improved by an instructional design that reduces extraneous cognitive load, the improvement may have occurred because the additional working memory capacity freed by the reduction in extraneous cognitive load has now been allocated to germane cognitive load. As a consequence of learning through schema acquisition and automation, intrinsic cognitive load is reduced. A reduction in intrinsic cognitive load reduces total cognitive load, thus freeing working memory capacity. The freed working memory capacity allows the learner to use the newly learned material in acquiring more advanced schemas. A new cycle commences; over many cycles, very advanced knowledge and skills may be acquired.

Such alterations in expertise also have profound instructional implications that were realized in the late 1990s. Until that time, research had focused on rather static situations in which novices were confronted with high-interactive materials resulting in a fixed level of intrinsic cognitive load, which could not be altered by instructional manipulations. Although it was stated theoretically, the changes in cognitive load that occurred as a function of increasing learner's expertise were not considered from an instructional perspective. Within this static focus, two instructional goals can be characterized. Initially, cognitive load research was aimed at the development of instructional techniques to reduce extraneous cognitive load. The goal specificity, worked examples, completion, split-attention, redundancy, and modality effects are the fruits of these research efforts. Under the assumption of a fixed intrinsic load and working memory capacity, the successful reduction of extraneous load naturally leads to the hypothesis that the freed capacity could be deployed for techniques that increase germane cognitive load. Employing example variability and prompting imagination are instructional techniques that have been used to substitute extraneous load with germane load.

With the publication in the late 1990s of research on levels of expertise in instructional design, a second, more dynamic line of cognitive load research began to materialize. The dynamic approach provides an opportunity for researchers to consider intrinsic load as a property of the task–subject interaction, which is open to instructional control. Typically, research within this line studies instructional techniques that take into account the alterations in the cognitive load that occur as learners' levels of expertise increase to facilitate the transition from novice to expert. The dynamic line's main outcome can be summarized as the expertise reversal effect, indicating that instructional techniques that are effective with novices can lose their effectiveness and even become ineffective when used with more experienced learners.

In one way or another, the articles in this special issue reflect this theory. The first three articles are all directly concerned with this new, major concern of CLT: How should instructional design be altered as a learner's knowledge increases? Schematic information held in long-term memory will, as just indicated, have dramatic consequences on the characteristics of working memory. What, in turn, are the instructional consequences?

The article by van Merriënboer, Kirschner, and Kester addresses this issue by beginning with the premise that learners should be presented realistic tasks despite the fact that, when dealing with complex areas, realistic tasks presented to novices with only limited schematic knowledge are likely to impose a heavy cognitive load. Van Merriënboer et al. suggest two forms of *scaffolding* to take into account when considering the alterations in cognitive load that occur with experience in a domain. The intrinsic aspects of cognitive load can be reduced by the scaffold of simple-to-complex sequencing, whereas the extraneous aspects can be reduced by providing the substantial scaffolding of worked examples initially, followed by completion problems and then full problems. (As mentioned next, Renkl & Atkinson describe a related fading procedure.) In addition, van Merriënboer et al. indicate that the timing of essential information presented to students can be critical from a cognitive load perspective, with inappropriate timing unnecessarily increasing load. They suggest that general, overarching supportive information be presented first so that learners can construct a schema to be used throughout the task, whereas specific procedural information should be presented only at the particular point when it is required. Lastly, the authors present their four-component instructional design model that integrates the various instructional design principles outlined in their article.

The use of worked examples rather than solving the equivalent problems is one of the earliest and probably the best known cognitive load reducing technique. Renkl and Atkinson are concerned with the role of worked examples when learning to solve particular classes of problems and, specifically, how that role should change as learners' levels of expertise increase. They suggest that in the earliest stages of learning, when intrinsic cognitive load is high because few schemas are available, learners should study instructions; during intermediate stages when schema formation has freed some working memory capacity, they should study worked examples and increase germane load by using self-explanations; in the final stages, there should be sufficient working memory capacity to permit more problem solving. Renkl and Atkinson describe the fading technique to facilitate the transition from the intermediate to final stages. Complete worked examples are faded by successively eliminating sections of the worked example until eventually only a full problem remains. The intermediate, faded worked examples are completion problems that are discussed in the van Merriënboer et al.'s article. This fading technique was found to be superior to the traditional procedure of alternating worked examples and problems.

Kalyuga, Ayres, Chandler, and Sweller review research directly concerned with the consequences of differing levels of expertise on cognitive load effects. They indicate that many instructional design recommendations proceed without an explicit reference to learner knowledge levels. Research is reviewed demonstrating that a large number of CLT effects that can be used to recommend instructional designs are only applicable to novices and can disappear and even reverse as a function of increasing expertise. Kalyuga et al. provide an overview of this so-called expertise reversal effect by coordinating and unifying multiple empirical observations of the interactions between instructional techniques and levels of learner expertise and show that the effect has a plausible theoretical explanation within a cognitive load framework.

Whereas the first three articles deal with issues traditionally considered by cognitive load theorists, Gerjets and Scheiter are concerned with procedures in which learners rather than instructors make instructional decisions. CLT usually has assumed that instructors rather than novice learners should decide what should be studied and how it should be studied. The worked example effect in which studying worked examples can be superior to solving the equivalent problems provides the clearest example. Nevertheless, as the first three articles indicate, there now is strong evidence that, as levels of expertise increase, it is appropriate to decrease instructor control and increase learner control. Under these circumstances, Gerjets and Scheiter's analysis with its emphasis on learner control is timely. They criticize the fact that CLT research typically assumes a one-to-one mapping between instructional design and a resulting pattern of extraneous and germane cognitive loads without taking into account other moderating variables, such as learner goals that interfere with this direct mapping. An extension to CLT is proposed along with the moderating factors of the configuration of teacher and learner goals and the learner's processing strategies that are used to accomplish these goals. Data from four experiments on hypertext instruction are summarized to support the claim that CLT should take these factors into account when making predictions for instructional material.

In their article, Mayer and Moreno show why CLT provides a very fruitful perspective in the area of multimedia learning. All too often, learners in multimedia environments experience cognitive overload when dealing with the complexity of text and pictorial presentations. Five overload scenarios are described; more importantly, theory-based and empirically proven solutions for each of these overload problems are offered. At the conclusion of their article, Mayer and Moreno suggest that techniques for measuring cognitive load are one of the most important issues that need to be addressed by CLT if it is to continue to provide a robust framework for instructional design. The last two articles, by considering this vital methodological issue, provide beacons to the future.

Brünken, Plass, and Leutner introduce a dual-task approach to the measurement of cognitive load in multimedia learning as a promising alternative to existing methods. They argue that learners' performance on a visual secondary reaction time task can be used as a direct measure of the cognitive load induced by multimedia instruction. They summarize two experiments that reproduced the modality effect in two different multimedia learning environments as a cognitive load effect, thereby demonstrating the feasibility of the dual-task approach. This approach may provide a viable alternative to the most commonly used measure of cognitive load, subjective task ratings.

The final article discusses the conceptual and practical issues associated with cognitive load measures. Paas, Tuovinen, Tabbers, and Van Gerven provide an overview of the different operationalizations of cognitive load and their advantages and disadvantages. Because a valid measurement of cognitive load is essential to the endeavor to further advance the empirical basis of cognitive load theory, their review of recent developments of cognitive load measurement is both important and timely. Finally, Paas et al. point out that assessing cognitive load is also helpful in the online adaptation of learning tasks in computer-based environments.

In its ability to generate a large range of novel, theory-based instructional design procedures, CLT is unique. Furthermore, because the ability of any scientific theory to generate applications tends to validate the original theory, the existence of the applications generated by CLT validates not only CLT but also many of the constructs of cognitive psychology, such as schema construction and the distinction between working and long-term memory. The articles in this special issue demonstrate that CLT is continuing its role of using cognitive psychology principles to generate novel instructional design procedures.