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Edited by Jan L. Plass, Roxana Moreno and Roland Brunken
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INTRODUCTION

What is Cognitive Load Theory (CLT)? The objective of CLT is to predict learning outcomes by taking into consideration the capabilities and limitations of the human cognitive architecture. The theory can be applied to a broad range of learning environments because it links the design characteristics of learning materials to principles of human information processing. CLT is guided by the idea that the design of effective learning scenarios has to be based on our knowledge about how the human mind works. Starting from this premise, different processes of knowledge acquisition and understanding are described in terms of their demands on the human cognitive system, which is seen as an active, limited-capacity information processing system. Taking into account the demands on cognitive resources induced by the complexity of the information to be learned, the way in which the instruction is presented to the learner, and the learner's prior experience and knowledge, CLT aims to predict what makes learning successful and how learning can be effectively supported by teaching and instruction.

Because of its applicability for a broad range of instructional materials, including Web-based and multimedia instruction, CLT is a frequently discussed concept in educational psychology and applied learning sciences. A growing body of empirical research has become available in recent years that describes the relationships among human cognitive architecture, the design of educational materials, and successful learning. Moreover, the research conducted in past years has led to a more detailed description of the theoretical components of CLT, including processes of schema acquisition, capacity limitations, and different causes for load, namely, intrinsic load (generated by the difficulty of the materials), extraneous load (generated by the design of the instruction and materials), and germane load (the amount of invested mental effort).

Considering the theoretical and empirical developments that have been made in this area, as well as the importance of the implications of CLT for the design of learning environments, especially for those using Web-based or multimedia formats for the delivery of instruction, there is a need to present the current knowledge about CLT in a handbook for research, education, and application. This edited volume brings together the most prolific researchers from around the world who study various aspects of cognitive load to discuss current theoretical as well as practical issues of CLT.

The book is divided into three parts: The first part describes the theoretical foundation and assumptions of CLT, the second part examines the empirical findings about the application of CLT to the design of learning environments, and the third part concludes the book with a discussion and directions for future research.

The chapters in the first part of this book discuss the theoretical underpinnings of CLT. In Chapter 1, Moreno and Park place CLT into the broader context of the learning sciences by providing a historical review of the assumptions underlying CLT and by relating the theory to other relevant theories in psychology and education. In Chapter 2, Sweller presents five assumptions underlying CLT using an analogy between evolution by natural selection and human cognitive architecture. Specifically, the chapter describes Sweller's most recent information store, borrowing, randomness as genesis, narrow limits of change, and environment organizing and linking CLT assumptions (Sweller, 2004). In addition, Chapter 2 describes the three categories of cognitive load and the additive load hypothesis, according to which intrinsic, extraneous, and germane cognitive load add to produce a total cognitive load level during learning. In Chapter 3, Kalyuga describes more fully the process of schema acquisition according to CLT and presents three instructional principles in its support: the direct initial instruction principle, the expertise principle, and the small step-size of knowledge change principle. In Chapter 4, Plass, Kalyuga, and Leutner expand on the first three chapters by offering a typology of individual differences that may have an effect on learners' working memory capacity. To this end, they distinguish between differences in information gathering, information processing, and regulation of processing and explain how such differences may affect cognitive load during learning. Taken together, the first four chapters of this book synthesize the history of CLT, describe the main principles underlying the current CLT, highlight the relation of CLT to individual learner differences, and relate CLT to other theoretical models.

As Sweller argues in Chapter 2, not only is the type of load imposed by the difficulty of the material (intrinsic load) and the instructional design (germane or extraneous loads) critical to CLT, but the learner's prior knowledge is as well. Information or instructional activities that are crucial to novices may interfere with further learning by more expert learners, giving rise to the expertise reversal effect (Kalyuga, Chapter 3, this volume). Instructional methods that promote schema acquisition in novices (leading to increased germane cognitive load) may contribute to extraneous cognitive load for more expert learners. Moreover, as Plass, Kalyuga, and Leutner argue in Chapter 4, cognitive load is most likely to arise when spatial ability is low or when students do not have good metacognitive skills. In sum, the relationship between the three types of load and learners' characteristics is far from simple.

The second part of this book synthesizes the findings of recent empirical studies conducted by the leading researchers in the cognitive load field and translates the insights gained from this work into guidelines for the design of learning environments. In Chapter 5, Renkl and Atkinson summarize research in which CLT is used to design learning environments that promote problem solving with worked-out examples. In Chapter 6, Kester, Paas, and van Merriënboer summarize research in which CLT is used to design learning environments that promote complex cognitive processes such as air traffic control systems. Finally, Chapters 7 and 8 summarize the research program of Mayer and Moreno, who have developed a set of empirically based principles to reduce intrinsic and extraneous cognitive load (Chapter 7) and increase generative processing (Chapter 8) in multimedia learning.

CLT began as an instructional theory that, based on assumptions regarding the characteristics of the human cognitive architecture, was used to generate a series of cognitive load effects in randomised, controlled experiments. Some examples are the modality effect, according to which multiple sources of information that are unintelligible in isolation result in less learning when they are presented in single-modality as opposed to dual-modality format (Low & Sweller, 2005; Mayer & Moreno, Chapter 7, this volume); the redundancy effect, according to which the presence of information that does not contribute to schema acquisition or automation interferes with learning (Mayer & Moreno, Chapter 7, this volume; Sweller, 2005); and the worked example effect, according to which studying worked examples promotes problem solving compared with solving the equivalent problems (Renkl, 2005; Renkl & Atkinson, Chapter 5, this volume). The fact that each one of these cognitive load effects was replicated across a variety of learning environments and domains led cognitive load researchers to derive corresponding evidence-based instructional principles. CLT can, therefore, provide instructional designers with guidelines for the design of multimedia learning environments that include verbal representations of information (e.g., text, narrated words) and pictorial representations of information (e.g., animation, simulation, video, photos), as well as for the design of Web-based learning environments. The research reviewed in the second part of this volume focuses on empirical work that applied CLT to multimedia and online learning environments.

According to CLT's additivity hypothesis, learning is compromised when the sum of intrinsic, extraneous, and germane loads exceeds available working memory capacity and any cognitive load effect is caused by various interactions among these sources of cognitive load. For example, many cognitive load effects occur because a reduction in extraneous cognitive load permits an increase in germane cognitive load, which in turn enhances learning. This is presumably the underlying cause of the redundancy effect reviewed by Mayer and Moreno in Chapter 7. However, these effects only occur when intrinsic cognitive load is high. If intrinsic cognitive load is low, sufficient working memory resources are likely to be available to overcome a poor instructional design that imposes an unnecessary extraneous cognitive load. Kester, Paas, and van Merriënboer (Chapter 6, this volume) explore this hypothesis by examining cognitive load effects in complex instructional environments. Ideally, good instructional design should reduce extraneous cognitive load and use the liberated cognitive resources to increase germane cognitive load and learning. Renkl and Atkinson (Chapter 5, this volume) explore this hypothesis by examining cognitive load effects in worked-out example instruction (aimed at reducing extraneous cognitive load) that includes different cognitive activities to engage students in deeper learning (aimed at increasing germane cognitive load). As Moreno and Park describe in Chapter 1, the empirical findings produced by cognitive load researchers over the past twenty years motivated a series of revisions of CLT since its inception.

The third part of the book includes chapters that discuss the current state of CLT as well as open questions for future developments. In Chapter 9, Brünken, Seufert, and Paas discuss the general problem of measuring cognitive load, summarize the different types of measures that are commonly used, and discuss current issues in cognitive load measurement, such as the problem of global versus differential measurement of the three types of cognitive load and the relationship between cognitive load and learners' prior knowledge. A critical evaluation of CLT from the perspective of the broader field of educational psychology and cognitive psychology is provided by Clark and Clark in Chapter 10. In Chapter 11, Horz and Schnotz compare CLT with other theoretical models used in the field of instructional design, namely Mayer's (2005) cognitive theory of multimedia learning and Schnotz's (2005) integrated model of text and picture comprehension. The last chapter of this volume presents some current open questions in cognitive load research (Brünken, Plass, & Moreno, Chapter 12).

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New York, Albuquerque, and Saarbrücken
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PART ONE

THEORY

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1

Cognitive Load Theory: Historical Development and Relation to Other Theories

ROXANA MORENO AND BABETTE PARK

The goal of this introductory chapter is to provide a historical review of the assumptions underlying Cognitive Load Theory (CLT) and to place the theory into the broader context of the learning sciences. The chapter focuses on the theoretical developments that guided the research on cognitive load and learning for the past twenty years and is organized in the following way. First, we examine the nature of the cognitive load construct and compare it to similar psychological constructs. Second, we present a historical review of the development of CLT's assumptions in the following four stages: (a) extraneous cognitive load in problem solving, (b) intrinsic cognitive load and the first additivity hypothesis, (c) germane cognitive load and the second additivity hypothesis, and (d) the evolutionary interpretation of CLT. Finally, we conclude the chapter by examining the constructs and assumptions of CLT in relation to other theories in psychology and education.

THE COGNITIVE LOAD CONSTRUCT

CLT is a psychological theory because it attempts to explain psychological or behavioral phenomena resulting from instruction. Psychological theories are concerned with the possible relationships among psychological constructs or between a psychological construct and an observable phenomenon of practical consequence. A psychological construct is an attribute or skill that happens in the human brain. In CLT, the main constructs of interest are *cognitive load*, hence the name of the theory, and *learning*. CLT was developed to explain the effects of instructional design on these two constructs.

The idea of cognitive load, however, was not new at the time the theory was developed. A similar psychological construct called "mental load" was already defined in the human factors psychology domain by Moray (1979) as the difference between task demands and the person's ability to master these demands. The mental load construct is essential to the human factors science, which is concerned with understanding how human-specific physical, cognitive, and social properties may interact with technological systems, the human natural environment, and human organizations. The relation of mental load or workload and performance has been investigated in many fields, including cognitive ergonomics, usability, human computer/human machine interaction, and user experience engineering (Hancock & Desmond, 2001; Hancock & Meshkati, 1988; Huey & Wickens, 1993; Wickens & Hollands, 2000). Likewise, the construct of task difficulty was used to refer to the mental load experienced during performance with the practical goal of developing measures of job difficulty for several professional specialties (Madden, 1962; Mead, 1970). The influence of this work in the development of CLT is clear. For instance, the development of the first subjective cognitive load scale (Paas & van Merriënboer, 1994) was inspired by a previously developed scale to assess perceived item difficulty in cognitive tests (Bratfisch, Borg, & Dornic, 1972).

After conducting a careful review of the human factors literature, MacDonald (2003) concluded that mental workload is more than just the amount of work that has to be done to accomplish a task. Other psychological factors, such as demand expectations, the actual effort expended during performance, and the perceived adequacy of performance, need to be taken into consideration when predicting mental load. For example, even if the amount of work that needs to be done to accomplish a task is high, different workload levels will result from individual differences in the willingness to spend effort on such a task. This willingness will depend on, among other factors, the learner's self-schemas and how relevant the task is perceived to be in terms of helping the learner achieve meaningful, personal goals (Eccles, Wigfield, & Schiefele, 1998; Thrash & Elliott, 2001).

The cognitive load construct is similar to the workload construct in that it takes into consideration the demands that a certain task imposes on an individual. However, it does not take into consideration the psychological effects that individuals' beliefs, expectations, and goals have on their load perceptions. This has been argued to be one of the limitations of CLT (Bannert, 2002; Moreno, 2006). Early psychological theories have recognized the multidimensional nature of the mental load construct by defining it as the psychological experience that results from the interaction of subjective individual characteristics and objective task characteristics (Campbell, 1988; Wood, 1986). In the words of Kantowitz (1987), mental load is "a

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subjective experience caused by . . . motivation, ability, expectations, training, timing, stress, fatigue, and circumstances in addition to the number, type and difficulty of tasks performed, effort expended, and success in meeting requirements" (p. 97).

CLT has mostly focused on how the objective characteristics of the task affect cognitive load and, in turn, learning. The only individual characteristic that is explicitly included in its theoretical framework is students' prior knowledge (Kalyuga, Chandler, & Sweller, 1998). Other individual characteristics that are highly predictive of learning, such as cognitive abilities and styles, self-regulation, motivation, and affect, are not considered within the CLT framework (Moreno, 2005). Nevertheless, several studies have examined additional individual differences that are relevant to cognitive load and learning (see Chapter 4, this volume).

THE STAGES OF CLT DEVELOPMENT

Stage I: Extraneous Cognitive Load in Problem Solving

Traditional CLT focused on the relation between the type of cognitive processes elicited by different problem-solving methods and schema acquisition. Although not fully developed as a theory, the first articles using the term cognitive load date to the late 1980s (Sweller, 1988, 1989). In this work, the founder of CLT, John Sweller, focused on the cognitive demands of the means–ends analysis method used in conventional problem-solving practice, a method in which learners independently solve a large number of problems to develop expertise. Using a production system approach, Sweller argued that means–ends analysis imposes a higher cognitive load on students' limited cognitive processing capacity than using a non-specific goal strategy to solve problems. The theoretical conclusion was that the cognitive effort spent in means–ends analysis leads to problem solution (the goal of the immediate task) but does not leave sufficient cognitive resources for schema acquisition (the goal of instruction). Therefore, the first hypothesis raised by CLT established a relationship between the instructional methods used to promote problem solving and the cognitive load induced by such methods. More specifically, "cognitive processing load is an important factor reducing learning during means-ends analysis" (Sweller, 1988, p. 263).

Later empirical studies cite the 1988 and 1989 articles as the main reference to CLT and further elaborate on its initial ideas. For instance, Sweller, Chandler, Tierney, and Cooper (1990) state that CLT "is concerned with how cognitive resources are distributed during learning and problem solving.