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Bridging Cognitive Load and Self-Regulated Learning Research: A complementary approach to contemporary issues in educational research

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ABSTRACT

The aim of this Introduction to the Special Issue 'Bridging Cognitive Load and Self-Regulated Learning Research' is to explore how cognitive load theory, which is particularly relevant for how learners deal with complex information, and self-regulated learning theory, which is particularly relevant for how learners use information to monitor and control their learning, can be combined into one joint research paradigm that is relevant for contemporary and future developments in education. The first two sections introduce cognitive load theory and self-regulated learning theory. The third section discusses the main similarities and differences between the theories, and describes how the *cue-utilization framework* can be used as the basis for a joint research paradigm. The main idea postulated is that new instructional methods should help learners identify diagnostic *cues* in available information that provide an accurate indication of where learners stand in relation to criterion task performance. Use of these diagnostic cues when monitoring learning will lead to better regulation of learning activities and of mental resources allocated, and thus to more efficient learning and higher learning outcomes.

In the fourth section, the six studies and two commentaries presented in this special issue are positioned within this paradigm. In the fifth and final section, a common research agenda based on the joint CLT-SRL paradigm is sketched and its relevance for future developments is explained. The studies presented in this special issue and the two commentaries, which complete the Special Issue, should be seen as a very first step in executing this research agenda.

1. Introduction

Learning in the 21st century is in many ways identical to learning in any other era. That is, only when elaborate processing of information and deliberate practicing of skills take place, either individually or in a community, will learners develop competencies transferable to other tasks at later times. Learning conditions have changed considerably, however, and these 21st century differences can be characterized by at least two phenomena. First, the amount of available information has increased and continues to increase dramatically. According to estimations, more information has been produced in the last 30 years than in the 5000 preceding years (Jungwirth, 2002). Therefore, the necessity of adequate literacy skills is becoming ever more obvious. Over the last decade, this information explosion has come to include personal information (e.g., movement, studying, sleeping, emotions; Zhu, Satizabal, Blanke, Perez-Uribe, & Troster, 2016, and even EEG; Dikker et al., 2016). This change in learning conditions changes the goals of education with less emphasis on transmission of information, and more emphasis on development of domain-general skills, such as literacy skills and self-directed learning skills.

This shift in 21st century learning conditions and goals raises novel educational questions related to how teachers and educational technologies can aid in this process. Specific questions posed include: How does the information explosion affect learning and performance? And, how should feedback in a digital learning environment be designed to enable the learner to act upon it? Given the multifaceted nature of these questions, they ask for integration of research paradigms and theoretical frameworks. Specifically, these issues relate to models of instructional design

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and cognitive load, which deal with learning in complex and information-rich environments (Sweller, van Merriënboer, & Paas, 1998), and models of Self-Regulated Learning (SRL), which deal with students' monitoring and control of their learning processes (Bjork, Dunlosky, & Kornell, 2013; Winne & Hadwin, 1998). In the current special issue, these two research pillars are combined to present work on their interface and to discuss how aligning them can provide a novel theoretical ground for contemporary issues in educational science.

Consider a 13-year old high school student who is motivated to teach herself to program a website for her volleyball team. To do so, she needs to determine how to develop her skill acquisition (e.g., asking a skilled friend or teacher, selecting an online course, watching YouTube videos). She will likely need to examine several types of information; textual, visual, and auditory, and continuously monitor her progress in relation to her end goal; a fully functional website. In this editorial, we build upon the example of self-teaching programming skills, because it provides a prototypical example of a contemporary skill and because it relates closely to both the instructional design issues that CLT research tackles, and monitoring and regulation issues pertinent in SRL research. On the one hand, the student must be supported in *making sense* of the wealth of verbal and visual information she is confronted with. Relevant cognitive-load principles then include the multimedia principle (i.e, use a combination of text and pictures rather than only text or only pictures), the split attention principle (i.e., integrate necessary information sources in space or time), and the signaling principle (i.e., highlight pieces of information the learner should pay attention to; for an overview of principles, see Mayer, 2014). On the other hand, the student must be supported in her *use of* selected information for improving own learning and performance. Effectively teaching yourself to program thus requires the ability to monitor own learning and the ability to control or regulate own behavior on the basis of rich and complex information. Educational interventions for improving this process should also study motivation for being involved in these complex cognitive and metacognitive processes (Whittaker et al., 2012).

Bringing together two fields of research can only be accomplished when there is sufficient common ground between them, and when they can profit from each other's strengths. Both educational research pillars have a history of over 25 years of dense scientific output, which has led to insights into the learning mind and how education can adapt to it. Both are based in the psychology of learning and memory, both use subjective estimates of learners about study behavior (i.e., invested mental effort, judgments of learning), and both focus on the self-directed learning situation. Both have their unique strengths: the field of instructional design in studying how cognitive resources relate to learning problem solving skills, and the field of self-regulated learning in studying how subjective judgments relate to objective performance. It has cost 25 years to bring CLT and SRL research to where they are now. Development of a combined theoretical approach and research paradigm and generation of robust insights will probably take at least a similar amount of time.

Below, we will first describe the fundamentals of Cognitive Load Theory and Self-Regulated Learning Theory. Afterwards, we analyze how these two theoretical frameworks can be combined. We then describe the topics of the papers in this special issue and what research questions could be answered by combining CL and SRL research. We end this editorial by applying these insights to the issue of educational research on self-teaching programming skills.

2. Cognitive Load Theory

Cognitive Load Theory (CLT) was initially developed in the 1980s (Sweller, 1988). It aims to develop instructional design guidelines based on a model of human cognitive architecture that is broadly supported by research in cognitive psychology and which can be explained from an evolutionary perspective (Sweller, 2008). CLT assumes that the human cognitive system has a severely limited working memory for “the retention of a small amount of information in a readily accessible form” (Cowan, 2014, p. 197). The capacity of working memory is limited by storage (i.e., only a very small number of information elements can be simultaneously active), duration (i.e., information elements quickly decay unless they are refreshed by rehearsal), and possibly other cognitive mechanisms (Shipstead, Lindsey, Marshall, & Engle, 2014). The theory emphasizes that these working memory limitations only apply to novel information obtained through sensory memory. Working memory has no known limitations when dealing with information retrieved from long-term memory. Long-term memory holds cognitive schemas that vary in their degree of complexity and automation. Human expertise comes from knowledge organized by these schemas, *not* from an ability to engage in reasoning with many elements that have not been organized in long-term memory - human working memory simply is not able to process many elements.

Expertise develops as learners combine simple schemas into more complex ones. These schemas organize knowledge but also heavily reduce working memory load because even a highly complex schema can be dealt with as *one* element in working memory. Schemas can be constructed by the learner by bringing elements together (i.e., chunking), by incorporating new elements in schemas already available in long-term memory (i.e., elaboration) or, more commonly, by obtaining already schematized information from other people. Schemas can then be treated as one single element in working memory and thus heavily decrease cognitive load. Constructed schemas may become fully automated if they are repeatedly applied and yield desired results. As is the case for schema construction, automation can free working memory capacity for other activities because an automated schema, acting as a central executive, directly steers behavior without the need to be processed in working memory. Because automation requires a great deal of practice, automated schemas only develop for those aspects of performance that are consistent across task situations. Thus, from an instructional design perspective, well-designed instruction should not only encourage schema construction but also schema automation for those aspects that are consistent across tasks (Van Merriënboer & Kirschner, 2013).

The ease with which information may be processed in working memory is a focus of CLT. Working memory load is affected by different processes yielding intrinsic, extraneous, or germane cognitive load (Sweller, van Merriënboer, & Paas, 1998; Van Merriënboer & Sweller, 2005). *Intrinsic load* is a direct function of the complexity of the performed task and the expertise of the learner; it cannot be altered without altering the task to be learned (e.g., by simplification) or by the act of learning itself. It depends on the extent of element interactivity of the materials or tasks that must be learned. The only way to reduce intrinsic cognitive load is to develop schemas that incorporate the interacting elements. *Extraneous load* is a result of superfluous processes that do *not* contribute to learning. It may be imposed, for example, when learners must integrate information sources that are distributed in place or time. *Germane load*, finally, is caused by effortful learning processes that deal with intrinsic cognitive load by adding elements to working memory that are relevant for learning, either from long-term memory (i.e., elaboration) or from the learning context (i.e., generalization from multiple cases).

CLT assumes that the different types of cognitive load are additive. Whereas CLT may not be relevant to teaching simple tasks, it

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