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Learner and Information Characteristics in the Design of Powerful Learning Environments

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SUMMARY

This themed issue aims to present some current directions in cognitive load research. The contributions to this issue represent a compilation of symposia contributions to the 11th European Conference for Research on Learning and Instruction (EARLI), 2005, in Nicosia, Cyprus. These cognitive load symposia were focused on empirical and theoretical perspectives on designing powerful learning environments by aligning learner characteristics, information characteristics, or both with the knowledge structures underlying the cognitive architecture. This article provides an introduction to cognitive load theory and the instructional design consequences of these characteristics, and a short overview of the contributions to this issue. Copyright © 2006 John Wiley & Sons, Ltd.

The central notion of cognitive load theory (CLT: Paas, Renkl, & Sweller, 2003, 2004; Sweller, 1999, 2004) is that if individuals are to learn effectively in a learning environment, the architecture of their cognitive system, the learning environment, and interactions between both must be understood, accommodated and aligned. The theory focuses on complex cognitive tasks, in which instructional control of cognitive load is critically important to meaningful learning. To realize this control, CLT uses current knowledge about the human cognitive architecture to generate instructional techniques. This architecture consists of an effectively unlimited long-term memory (LTM), which interacts with a working memory (WM) that is very limited in both capacity and duration; for new, yet to be learned information, the processing capacity is limited to only 4 plus or minus 1 element, and if not rehearsed, the information is lost within 30 seconds (Cowan, 2001). LTM contains cognitive schemas that are used to store and organize knowledge by incorporating multiple elements of information into a single element with a specific function. Skilled performance develops through the building of increasing numbers of ever more complex schemas by combining elements consisting of lower level schemas into higher level schemas. If the learning process has occurred over a long period of time, the schema may incorporate a huge amount of information. Because a schema can be treated by working memory as a single element, the limitations of WM disappear for more knowledgeable learners when dealing with previously learned information stored in LTM.

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The design of powerful learning environments, in which instructional conditions are aligned with the cognitive architecture, requires understanding of the learner characteristics that affect the underlying knowledge structures and their interactions with the learning task. Not surprisingly, learner expertise has been identified by cognitive load researchers as a key characteristic to consider in the design of instructional techniques (for an overview see, Kalyuga, Ayres, Chandler, & Sweller, 2003). Kalyuga et al. (2003) have described a phenomenon called the expertise reversal effect, indicating that the effectiveness of instructional techniques depends very much on levels of learner expertise. Instructional techniques that are effective with inexperienced learners can lose their effectiveness and even have negative consequences when used with more experienced learners. So, as novice learners gain expertise, their requirements in learning materials change in accordance with their capacity for cognitive load.

Another learner characteristic that is known to impact the knowledge structures underlying the cognitive architecture is learner age. This characteristic is particularly important in the context of the topical focus on lifelong learning. One of the central findings of cognitive ageing research is that the efficiency of cognitive operations declines with age in adults. A general and robust effect of cognitive ageing research is that age-related declines in cognitive performance are most likely to emerge in complex cognitive tasks requiring effortful processing (Perfect & Maylor, 2000). The most prevalent explanations for the age-related cognitive declines are based on reduced WM capacity (e.g. Salthouse, Mitchell, Skovronek, & Babcock, 1989), slowed processing speed (e.g. Salthouse, 1996), difficulties inhibiting responses to irrelevant information (e.g. Hartman & Hasher, 1991), and deficits in integrative aspects of WM (e.g. Mayr, Kliegl, & Krampe, 1996). In general, the challenge of cognitive load researchers is to find instructional techniques that reduce the performance gap between young and old learners engaged in complex tasks (see e.g. Paas, Camp, & Rikers, 2001; Van Gerven, Paas, Van Merriënboer, & Schmidt, 2002). To that end, Paas, Van Gerven, and Tabbers (2005) have systematically mapped age-related cognitive declines on the potentially compensatory strategies that are offered by CLT.

CLT argues that the interactions between learner and information characteristics can manifest as *intrinsic* or *extrinsic cognitive load* (for an overview see, Paas, Tuovinen, Tabbers, & Van Gerven, 2003). Intrinsic cognitive load is determined by the level of element interactivity of the information presented by a learning task, that is, the number of elements a learner has to attend to simultaneously to understand the learning material. With increasing expertise learners are able to deal with configurations of interacting elements as single units, thereby decreasing the intrinsic load of a task. So, intrinsic load is supposed to be determined by an interaction between the nature of the material being learned and the expertise of the learners. It cannot be directly influenced by instructional manipulations; only a simpler learning task that omits some interacting elements can be chosen to reduce this type of load. Although the omission of essential, interacting elements will compromise sophisticated understanding, it is considered unavoidable with very complex tasks that present high element interactivity information. Sophisticated understanding can only commence if, after subsequent additions of omitted elements, eventually, the learner is able to process all essential elements simultaneously.

Besides the task-related intrinsic load, the manner in which the task information is presented to learners and the learning activities required of learners impose an instructional design-related extrinsic cognitive load. Where that load is unnecessary and so interferes with schema construction and automation, it is referred to as *ineffective or extraneous.* Where the extrinsic load fosters schema construction and automation, it is referred to as *effective or germane*. Intrinsic and extrinsic cognitive load are additive in that together, the total load cannot exceed the working memory resources available if learning is to occur. That is why extraneous load is primarily important when intrinsic load is high because intrinsic and extrinsic load are additive. If intrinsic load is low, levels of extraneous load may be less important because total cognitive load may not exceed working memory capacity, and learners may be able to compensate for poor instructional design. As a consequence, instructional designs intended to manage cognitive load are primarily effective with complex cognitive tasks that present high element interactivity information. Extraneous and germane load can work in tandem in that, for example, a reduction in extraneous cognitive load can free capacity for an increase in germane cognitive load.

Whereas, instructional strategies to lower extraneous load are well documented (see Sweller, Van Merriënboer, & Paas, 1998), strategies to induce germane load, and particularly, strategies to manage intrinsic load have only recently come to the attention of cognitive load researchers. With regard to intrinsic load, the general opinion up to now is that it should only be reduced if, even after removal of all sources of extraneous cognitive load, the element interactivity of the complex task-related information is still too high for efficient learning. In practice, this means that CLT recommends instructional designers or teachers to use germane load inducing methods only in combination with relatively simple tasks, in which the simultaneous processing of all interactive information elements leaves some spare cognitive capacity. However, there is hardly any information available about how intrinsic cognitive load can be reduced effectively. An exception is a theoretical framework presented by Van Merriënboer, Kirschner, and Kester (2003), which identifies simple-to-complex versions of the whole task as an approach to decrease intrinsic cognitive load.

It is becoming clearer that the cognitive load effects found so far are highly dependent on characteristics of the learner and the information presented by the task. In fact, it appears that the different types of cognitive load can only be reliably categorized with knowledge of these characteristics. That is why we believe that research efforts to advance CLT can only be successful if they consistently take these characteristics into consideration. The contributions to this themed issue either deal with learner characteristics, characteristics of the information presented in learning tasks, or both, and as such can be considered timely in the sense that they try to advance our understanding about the mediating effects of learner and information characteristics.

This themed issue begins with an article by Ayres, titled 'Impact of reducing intrinsic cognitive load on learning in a mathematical domain', which is one of the first studies investigating the effects of different approaches to reduce intrinsic load on learning. Two experiments focusing on the interaction between characteristics of the learner and the task information were conducted in the domain of mathematics. More specifically, groups of low and high prior knowledge were confronted with either part-tasks isolating the constituent elements, whole tasks fully integrating all elements, or mixed tasks progressing from part-tasks to whole tasks.

The Olina, Reiser, Huang, Lim, and Park article 'Problem format and presentation sequence: Effects on learning and mental effort among US high school students', reports an experiment that examined the interaction between format and presentation sequence of practice problems for lower and higher achieving students on learning of comma rules in a real classroom setting. They compared the learning outcomes of lower and higher achieving students who were presented (1) cued problems that reduce extraneous load or conventional problems in (2) a random problem presentation order that increases germane load or a blocked problem presentation order.

The article by Van Gerven, Paas, Van Merriënboer, and Schmidt, titled 'Modality and variability as factors in training the elderly', presents an investigation into the combined learning effects on a puzzle task of instructional modality and variability for young and elderly learners. Particularly, using both the visual and auditory modality was expected to reduce extraneous load and high-variability practice was expected to increase germane load, which leads to the hypothesis that this specific combination of instructional modality and variability would lead to the best learning results, especially for the elderly.

The Seufert and Brünken article 'Cognitive load and the format of instructional aids for coherence formation' focuses on the alignment of task information characteristics with the cognitive architecture by comparing the combined effects of two types of help and two types of support. The authors hypothesized that surface level help in the form of hyperlinks in combination with deep structure level help explaining the relations of corresponding structures would be the best instructional aid for constructing coherent mental representations.

The article by Kalyuga, titled 'Assessment of learners' organized knowledge structures in adaptive learning environments', focuses on tailoring instruction to levels of learner expertise by dynamically aligning learner and task information characteristics with the knowledge structures underlying the cognitive architecture. Two rapid assessment techniques that either adapted the learning tasks to the learner's performance or to the learner's performance in combination with the associated cognitive load were compared to a non-adaptive control condition.

The Van Merriënboer, Kester, and Paas article, 'Teaching complex rather than simple tasks: Balancing intrinsic and germane load to enhance transfer of learning', argues that in contrast to the general opinion that germane load should only be induced if the intrinsic load leaves enough spare capacity to profit from it, learning tasks should *always* be combined with methods that induce germane cognitive load. They argue that the element interactivity of learning tasks should be limited early in training to decrease intrinsic load, so that germane-load inducing methods might be used right from the start of the training programme.

Finally, the discussion articles by Sweller and Rikers close this themed issue.

We hope that the collection of articles in this themed issue makes cognitive load researchers realize that powerful learning environments can only be designed by using a CLT that provides guidelines for (dynamically) aligning characteristics of the learner and the information presented by the task with the cognitive architecture.

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