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Commentary

Managing cognitive load—recent trends in cognitive load theory

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1. Introduction

Cognitive Load Theory (CLT) is an internationally well known and widespread theory, which has been empirically confirmed in numerous studies. Kirschner, the guest editor of this issue, has been successful in obtaining papers of internationally acknowledged representatives of CLT, which give an excellent overview of the current state of the field. Moreover, the papers also show several ways of how learning can be optimised by means of instruction.

As Kirschner states in the introduction, CLT is based on cognitive theories of human architecture, and one major assumption is that a human's working memory has only a limited capacity. When learning, humans allocate most of their cognitive resources to this activity, and in many cases it is the instructional format which causes an overload. Consequently, the basic idea is to reduce such external load in order to make available more capacity for actual learning so that better learning and transfer performance is achieved. As described in this special issue, CL can arise from three sources. The first one is called "intrinsic cognitive load" (ICL) and is connected with the nature of the material to be learned. High ICL occurs in case of high element interactivity and when learners do not yet have sufficient command over appropriate schemata. The second source is called "extraneous cognitive load" (ECL) and has its roots in poorly designed instructional materials. Such ECL does not contribute to learning—instead it reduces working memory capacity for learning. The third source is referred to as "germane cognitive load" (GCL); it occurs when free working memory capacity is used for deeper construction and automation of schemata. In general, the main difference between contributions is the degree to which they are based on CLT; some encompass additional theoretical approaches

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and constructs. Further differences are the types of CL (i.e., ICL, ECL, GCL) investigated in connection with different instructional formats (worked examples, completion problems, etc.)

In the following I comment on the papers from two different perspectives: From the perspective of instruction I discuss the papers dealing with the *external management of CL* by means of optimal instruction. From the perspective of learning I discuss the papers dealing with the *internal management of CL* by learners' metacognitive and self-regulative competence. Furthermore, I argue that future research should focus more intensively on how learners deal with CL, not only to support them by adequate instructional design but also to enable the learners to deal with high CL or even overload.

2. Managing cognitive load

In principle, cognitive processes of working memory can be controlled externally by presenting certain instructional formats. For instance, one can control the input into working memory by presenting a certain type and amount of information within the instruction. Additionally, learners control CL internally, for example, when regulating the learning process by deciding what and how to learn. Moreover, a reduction of CL by ideal instructional format does not per se guarantee that all free mental resources will be allocated for deeper schema construction and automation. Thus, I argue that optimal management of cognitive resources must distinguish between *external management* through adequate instructional format and *internal management* based on adequate learners' strategies of dealing with high CL.

2.1. External management of cognitive load

2.1.1. The classical method: reduction of ECL

According to CLT, worked examples should be the superior training format compared to conventional practice problems since they reduce ECL. Because of working memory's decline in cognitive aging, van Gerven, Paas, van Merrienboer, and Schmidt (this issue) argue that especially elderly people should benefit from the worked examples training format. In general, the results of their experiment confirm this assumption, i.e. the training efficiency of the worked-examples group compared to the conventional-problems group was significantly higher for the elderly. Interestingly, the younger learner group did not profit from the worked-examples condition, which seemingly contradicts recent CLT-studies showing worked-example effects mainly for young learners (e.g., Sweller & Chandler, 1994; Sweller, van Merrienboer, & Paas, 1998). However, it is also possible that the younger learners had higher knowledge in the respective domain, i.e. that ICL was low. In this case positive effects of instructional measures of ECL-reduction will decrease (e.g., Marcus, Cooper, & Sweller, 1996). In further studies this interpretation problem can be avoided by controlling learners' prior knowledge.

Another major implication of the van Gerven et al. study is to validate in future

research their argument that the ECL-reduction-effect is even greater for learners with working memory declines. For example, the effects should also be obtained in disabled persons with capacity declines or in learners with a short working memory span. In addition, other powerful CLT-training formats which have been shown to reduce ECL, e.g. completion problems which are quite similar to worked examples, should also be examined as well as the split attention, redundancy, and modality effect.

The study of van Merrienboer, Schuurman, de Croock, and Paas (this issue) addresses completion problems and shows better training efficiency due to this ECL-reduction. Since their main focus lies not on ECL-reduction but rather on the combination of ECL-reduction and GCL-increasing, this contribution will be discussed in more detail below. However, here it must be pointed out that their study clearly confirms the positive effects of the external management of ECL-reduction.

New technologies make available new presentation formats (e.g., animation, narration, and cueing), which should improve learning. But too often computer-based learning environments are rather cluttered. Thus, the question arises whether the learner will be unnecessarily mentally overloaded by such formats or techniques, or in more general terms, by bad design. The contributions of Mayer and Moreno (this issue) and van Bruggen, Kirschner, and Jochems (this issue) address this continuously growing field of learning technologies and discuss their design with respect to CLT with the emphasis on ECL-reduction.

The paper of Mayer and Moreno (this issue) presents a review of several empirical studies investigating different design guidelines for multimedia learning environments. Based on their cognitive theory of multimedia learning, which relies not only on CLT but also on dual coding theory and constructivistic learning theory, five design principles for effective multimedia instructions are recommended which are fully in line with CLT (except the principle of multiple representation). Since they all lead to higher learning outcomes one can conclude that they are effective measures for the reduction of ECL in multimedia instructions.

A major difference between Mayer and Moreno's experiments and the other empirical contributions in this issue is that Mayer and Moreno did not measure learners' mental effort during learning. This might be due to the very short learning periods (e.g. 30s to 140s animation) and system-paced instead of learner-paced instruction. These are crucial aspects to be considered when interpreting the results in terms of CLT. For example, in a recent study investigating learner-paced multimedia instructions with longer training periods (about 70 minutes) even negative results for the modality principle were found (Tabbers, Martens, & van Merrienboer, 2000). Tabbers et al. lead their results back to different length of instructions and to different benefits of the modality principle with respect to the realised degree of learner control. Comparing their study with other studies, the authors argue that bimodal presentation is probably only advantageous in case of system-paced instruction, whereas the visual-only format is probably better for learner-paced instruction, where the learner can compensate higher ECL by scrolling back- and forward in the material. Although this interpretation must be substantiated in further studies, it calls attention

to the fact that the successful application of CLT-training formats depends on many aspects which require careful consideration.

Similarly, in future studies the question must be addressed whether the reported different effect sizes in Mayer's and Moreno's paper (e.g. ES=1.3 for contiguity aids compared to ES=0.90 for coherence aids) are really due to different impacts of the specific design principles. This is not only an important question for the theoretical development of CLT, but also for instructional designers of multimedia learning environments, who have to choose between several design principles or may combine several principles in designing a single multimedia instruction.

A completely new technical application is discussed in the paper of van Bruggen, Kirschner, and Jochems (this issue) which reflects the theoretical framework of CLT regarding the design of computer-supported collaborative learning environments (CSCL). The central idea is that CSCL consists of many shared external representations that have to be co-ordinated and integrated by the learner, which most probably induce high CL. The authors argue that the co-construction of external representations by different learners may result in poor learning outcomes, because it induces high CL. Instead of co-construction they propose the joint studying and discussion of worked out external representations to reduce ECL. However, one has to consider that co-construction activities, which are especially preferred by modern constructivist learning theories, have a somewhat different educational purpose than initial schema acquisition. Their educational function is mainly to construct and negotiate a shared meaning of a complex subject matter, which requires a certain amount of prior knowledge. Nevertheless, the authors address the problems of possible overload and disorientation for beginners in such complex environments.

Furthermore, it should be pointed out that van Bruggen et al. focus on social learning scenarios, in which several learners are involved in the learning processes. Obviously, it is much harder to control cognitive overload in such settings. This may also be the reason why CLT-assumptions are usually investigated in individual learning scenarios. Taking into account these social learning settings, future studies have to show whether worked out external representations as well as the other suggested measures of ECL-reduction in CSCL are adequate alternatives in the initial learning phases of novice learners.

2.1.2. A new approach: manipulation of ICL

The manipulation of ICL by instructional materials is a completely new approach and especially interesting, not only because it is proposed by the fathers of CLT but also because it contradicts their earlier assumptions by arguing that ICL can be artificially reduced with the help of appropriate information sequencing.

The contribution of Pollock, Chandler, and Sweller (this issue) investigates the manipulation of ICL when learning highly complex information. In the first part of instruction presented to learners, CL was reduced by not presenting the whole information at once; instead individual elements that could be processed serially were offered. In the second part of instruction, however, all information was presented at once and thus had to be processed simultaneously in working memory. In agreement with the authors' assumptions, this mixed method significantly improved training

efficiency and understanding in the long run compared to instructional formats which present all elements of information simultaneously from the very beginning. Although understanding decreased in the first phase of instruction, this paid off in the second phase in which better understanding was achieved. In general, the isolated-interacting elements procedure seems an adequate instructional technique to be used in the initial phase of instruction for beginners who lack rudimentary schemata. However, for experienced learners who already possess sophisticated schemas about the learning topic, its superiority vanished as expected by the authors.

Although this kind of external CL-management seems to be revolutionary from the perspective of CLT, the idea of adequate information sequencing is really an old one in educational psychology. For example, Bloom's learning taxonomy establishes six different learning objectives in a hierarchy where the learning of basic knowledge structures based on mere rote learning is essential for understanding. Also, for intellectual skills Gagne's learning hierarchy covers five different subcategories with higher-order rules at the top (for a recent review on this kind of instructional theory see Reigeluth, 1999). Moreover, sequencing theories (e.g., Reigeluth, 1983, 1987) deal with appropriate information sequencing in instruction so as to optimise learning. The value of Pollock's et al contribution is to re-interpret these older approaches by taking a closer look at the learners' cognitive architecture, that is to say working memory capacity. Future research dealing with CLT will surely be influenced by this work, since the manipulation of ICL offers an effective measure for the external management of CL.

As in van Gerven's et al. study, Pollock et al. also demonstrate the crucial role of learners' experience because they empirically obtained the effects only for novice learners, which is fully in line with CLT. Generally speaking, only in the case of high ICL will the effects of CLT-training formats be obtained either through adequate ECL-reduction and/or through artificially reduced ICL. The question whether learning material is characterised by high element interactivity, i.e. high ICL, can only be answered if learners' prior knowledge is taken into account (e.g. Sweller et al., 1998). Thus, here again the importance of controlling learners' pre-knowledge in future studies is pointed out.

2.1.3. Current trends: increasing GCL

Another promising approach for the external management of CL is the increase in GCL if the total amount of CL stays within the limits—either due to low ICL and/or due to low ECL. In this case, the "unused" working memory capacity should be used for schema construction and automation. This could be realised by optimising GCL, i.e. by stimulating the learner to elaborate the learning material more deeply, for example by presenting different problem task variants (Paas & van Merrienboer, 1994). Moreover, a recent trend in CLT-research is to simultaneously combine ECL-reduction with GCL-increase in training measures, thus 'redirecting' learners' attention from irrelevant extraneous cognitive processes to relevant germane processes of schema construction (e.g., van Merrienboer, 1997; DeCroock, van Merrienboer, & Paas, 1998).

Van Merrienboer, Schuurman, de Croock, and Paas (this issue) investigate the

idea of redirecting learners' attention, which is mainly based on the simultaneous management of ECL and GCL. In two experiments they first analysed the effects of ECL and GCL separately. In their first experiment they found higher training efficiency when learning with completion problems, which can be interpreted as effective ECL-reduction, as already mentioned above. Much more interesting here is the second experiment in which they increased GCL through learning with high contextual interference problems. As expected, this measure resulted in significantly higher CL compared to low contextual interference problems and a slight trend towards higher transfer performance. Finally, by means of a third experiment, van Merrienboer et al. tried to redirect learners' attention from extraneous to germane processes by simultaneously combining both guidelines in one training measure. In line with their assumptions, the results show that the optimal combination of both factors led to the highest training efficiency, however, not to the expected highest transfer performance.

In reference to the absence of positive effects in transfer performance in two of the three experiments one could conclude that the operationalisation of GCL-increase (especially when combined with ECL-reduction) must be conducted rather carefully. Thus, in a further study the same material should be used in all experiments. Only if significant transfer improvements can be obtained separately for ECL and GCL, should the effect of redirecting attention in combined training measures be examined; this procedure should lead to clearer results.

2.2. Internal management of cognitive load

Up to now the focus was on how learning can be optimised by means of instructional formats. However, one must consider the fact that learners also have strategies at their disposal to deal with high CL more or less effectively. Consequently, we shall address this so-called internal management of CL. When looking at the contributions commented on so far, one notices that the process measures consist of subjective mental effort ratings. However, these process measures do not give insights about how learners actually deal with high CL, i.e. how they handle their CL or even overload.

What has not been mentioned so far but which appears very important is the learner-control condition realised in the first experiment reported by van Merrienboer et al. (this issue). Learners in this treatment group were able to freely choose between training formats, i.e. between completion or conventional problems during learning. This is a rather promising approach in CLT-research. Interestingly, this learner-control group showed the best transfer performance. Maybe this is due to the fact that because of this flexible access to different training formats, learners are able to manage and regulate their CL much better. Unfortunately, no other learner-control treatment was realised in the other experiments. From the perspective of CLT-development, it appears very important to find out (not only in the studies of van Merrienboer et al. but also in the other contributions) which training format learners would choose if they were able to decide themselves and also to examine if learner-control treat-

ments would also be superior with respect to training efficiency and transfer performance.

The paper of Stark, Mandl, Gruber, and Renkl (this issue) contributes to the internal management of CL in a completely distinct but encouraging way. On the basis of the concept of mental effort, the authors interpret the results of an elaboration training which aims at improving worked example-based learning. Considering the fact that learners often do not study the instructional materials carefully (illusion of understanding), one can ask whether this phenomenon is also true when studying CLT-recommended training formats, e.g. worked examples. Actually, recent CLT-research which aims at decreasing ECL by means of certain training formats predominantly reports of better training efficiency and transfer performance (e.g., Sweller & Chandler, 1994; Sweller, 1999; contributions of this issue). So far, however, no detailed process analysis has been conducted showing how learners are really dealing with those CLT-formats. In Stark's et al. experiment, elaboration training resulted in better learning behaviour, thus one may conclude that learners in the non-training group did not elaborate worked examples as deeply as one may hope for.

Moreover, by means of analysing learners' verbal protocols by cluster analysis Stark et al. identified different patterns of example exploration. With the help of such learning profiles, the authors were able to demonstrate that successful learners reported deeper cognitive elaboration, more intensive monitoring processes as well as higher mental effort. Although only positive and negative monitoring have been considered as metacognitive aspects, the results of Stark et al's study should encourage other researchers to make use of such qualitative process analysis in future CLT-research, thus gaining a better understanding of how learners are really dealing with externally and internally caused CL. Such process analysis may be conducted by using thinking aloud methods, prompting for cognitive and metacognitive aspects during learning, or retrospective video analysis in addition to subjective mental effort ratings. Of course, some of these measures will also cause CL during learning (e.g. thinking aloud), however they would give important insights in learners' internal management of externally caused CL.

3. Summary and concluding remarks

The contributions in this special issue have been discussed with regard to the management of CL. In summary, the majority of the contributions investigate the worked example effect in order to reduce ECL. Furthermore, a new way of external management by artificially reducing ICL is discussed as well as the recent trend of managing an increase in GCL so as to redirect the learners' attention. This special issue highlights the crucial role of adequate design of computer-based learning environments which should rely on the recommended CLT-design principles. Finally, it was suggested to not only consider the external management of CL but also learners' internal management strategies. Thus, in order to further develop CLT the question of how learners really deal with CL should be addressed with the help of process analysis in future research.

Finally, an important conceptual differentiation should be emphasised, which has neither been discussed in this special issue nor in other CLT-studies. With respect to learning criteria, one may distinguish studies that aim at short term learning performance and studies that aim at long term skill development and competence acquisition. Earlier research mainly investigated ECL-reduction with short time learning periods focusing on learning performance measures within one task. In contrast, more recent work is increasingly studying complex skill development based on several problem tasks. In my opinion for short term learning performance the classical ECL-reduction effects (e.g., split-attention, redundancy, modality) appear to be more significant, whereas for long term skill development deeper elaboration processing induced by external GCL-management and/or effective internal management seem more effective measures. Future research on CLT also needs to consider this conceptually driven distinction.

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