Goal Configurations and Processing Strategies as Moderators Between Instructional Design and Cognitive Load: Evidence From Hypertext-Based Instruction

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Abstract

In this paper we propose some augmentations of Cognitive Load Theory (CLT) inspired by evidence from hypertext-based instruction. In particular, we focus on the role of goal configurations and processing strategies as moderators between instructional design and cognitive load. First, we describe pivotal assumptions of CLT and conceptual shortcomings related to these assumptions. Second, we review evidence from our own hypertext-based research that gives reasons for integrating configurations of teacher goals, learner goals, as well as processing strategies into CLT. These augmentations of CLT are necessary in order to account for the rather weak relation between instructional design and pattern of cognitive load that shows up in the context of self-controlled learning. CLT, augmented with the notion of learner control, can now better serve as a theoretical foundation for the design of hypertext-based instruction.

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Cognitive Load Theory: Pivotal Assumptions and Conceptual Shortcomings

Pivotal Assumptions of Cognitive Load Theory

Cognitive Load Theory (CLT) claims to be concerned with "the manner in which cognitive resources are focused and used during learning and problem solving" (Chandler & Sweller, 1991, p. 294). The theory's main goal is to guide instructional design decisions. CLT is based on a distinction between a potentially unlimited long-term memory and a working memory that is severely limited with regard to the number of cognitive elements that can be simultaneously held active (cf. Baddeley, 1992). Due to this restriction working memory is considered to be the bottleneck of learning in CLT because all information that is to be stored in long-term memory has to be processed in working memory first. In accordance with schema theory it is assumed that knowledge is stored in long-term memory in the form of schemas: "A schema categorizes elements of information according to the manner in which they will be used" (Sweller, van Merrienboer & Paas, 1998, p. 255). With regard to problem solving a schema is defined "as a construct that allows problem solvers to group problems into categories in which the problems in each category require similar solutions" (Cooper & Sweller, 1987, p. 348). Schemas can vary in their degree of automaticity that determines the amount of conscious effort necessary for their application. The construction and automation of schemas are considered to be the two main prerequisites of problem-solving expertise (cf.

VanLehn, 1996) and are therefore the most important goals of instruction according to CLT.

The relationship between schemas and working memory is two-fold: On the one hand, the construction of a new schema demands working-memory resources as it requires one to simultaneously process all information units that are to be integrated into that schema. On the other hand, once a schema exists it allows one to "increase the amount of information that can be held in working memory by chunking individual elements into a single element" (Sweller, 1994, p. 299). Therefore, schemas enable learners to treat arbitrarily complex or sophisticated information as a single working-memory unit. Furthermore, schema automation frees additional cognitive resources by allowing the application of schemas without conscious effort. The availability of a large number of highly automated schemas enables domain experts to engage in complex and demanding cognitive processes compared to novices who do not possess these schemas.

According to CLT different types of cognitive load imposed on working memory can be distinguished in instructional settings:

Intrinsic cognitive load: The first type of cognitive load refers to the number of elements that are to be integrated into a to-be-learned schema and therefore have to be processed in working memory simultaneously. How many cognitive elements have to be processed simultaneously for schema construction (this is denoted as element interactivity) depends on the relational complexity of the to-be-learned content and the learner's degree of expertise (i.e., schema availability): "Intrinsic cognitive load through element interactivity is determined by an interaction between the nature of the material

to-be-learned and the expertise of the learner" (Sweller et al., 1998, p. 262). An important feature of intrinsic cognitive load is that it cannot be altered by instructional design.

Beyond cognitive load that is associated with the intrinsic nature of the learning material there may be additional cognitive load that is imposed onto working memory due to the instructional presentation of the material and the activities the learner is engaged in. This load can be further subdivided according to whether it is beneficial for schema construction and automation or not.

Extraneous cognitive load: Extraneous or ineffective cognitive load is the result of implementing "instructional techniques that require students to engage in activities that are not directed at schema acquisition or automation" (Sweller, 1994, p. 299). A large amount of work in CLT has shown that many commonly used instructional tasks involve cognitive processes that are not helpful (or even hindering) for learning (e.g., search for a problem solution or search for referents in an explanation). With regard to hypertext-based instruction several factors can be identified that impose extraneous cognitive load onto the learner: "The use of hypertext features requires making decisions about what to read and the order for reading information. Many learners may not be proficient computer users and must, therefore, use cognitive resources to operate the computer" (Niederhauser, Reynolds, Salmen & Skolmoski, 2000, p. 251). Extraneous cognitive load may impede learning as it requires cognitive resources that may exceed the limits of working-memory capacity. Furthermore, cognitive resources required by extraneous cognitive load can no longer be devoted to mindful cognitive processes that are associated with a third type of cognitive load, namely germane cognitive load.

Germane cognitive load: When intrinsic task demands (resulting in intrinsic cognitive load) leave sufficient cognitive resources available, learners may "invest extra effort in processes that are directly relevant to learning, such as schema construction. These processes also increase cognitive load, but it is germane cognitive load that contributes to, rather than interferes with, learning" (Sweller et al., 1998, p. 264). Germane or effective cognitive load is due to beneficial cognitive processes like elaborations, abstractions, comparisons, and inferences that are encouraged by the instructional presentation. Germane cognitive load may further support schema construction by adding higher-level cognitive processes to the mere simultaneous activation of elements in working memory that are to be integrated into a schema.

According to CLT's analysis of cognitive demands in learning, two important objectives of instructional design can be derived (cf. Sweller et al., 1998, p. 264): First, instructional design must aim at reducing extraneous cognitive load, and second it must encourage learners to invest unused resources in higher-level cognitive processes that are associated with germane cognitive load. However, until now most work in CLT has focused on instructional designs intended to decrease extraneous cognitive load without considering how learners' attention may be directed toward processes that are relevant to learning. Whereas this is a practical shortcoming of CLT research that is being tackled in more recent work (cf. Sweller et al., 1998) there are theoretical issues that concern the conceptual foundation of CLT. These conceptual shortcomings of CLT will be discussed in the next section and will be illustrated with evidence from hypertext-based instruction.

Conceptual Shortcomings of Cognitive Load Theory

CLT research typically assumes a one-to-one mapping between instructional design and a resulting pattern of extraneous and germane cognitive load without taking into account moderating variables that interfere with this direct mapping. This assumption results from two premises: First, it is postulated that there is a predefined goal of instruction which is to foster schema construction and automation. Second, it is presupposed that a specific instructional design is strongly associated with a specific type of learner activity in the sense that it elicits, encourages, or induces this activity. No variability of learner activities as a reaction towards a specific instructional design is expected. As a result, the relation between instructional design and pattern of extraneous and germane cognitive load is seen as more or less deterministic (cf. Figure 1).

--- Insert Figure 1 here ---

In our view the relation between instructional design and cognitive load is far less deterministic than suggested by CLT because the relationship is moderated by the configuration of instructional or teacher goals and by the activities of the learner. The latter can be analyzed in terms of the configuration of learner goals and the processing strategies that are deployed to accomplish these goals.

Configuration of teacher goals: As has been already pointed out by Goldman (1991) the same instructional design may vary with regard to its suitability for the accomplishment of different instructional goals. Instructional goals are usually introduced by a teacher who determines the criteria according to which learning outcomes are

evaluated. For instance, teacher goals may include enabling literal recall (i.e., rote learning), acquisition of declarative knowledge, or transfer of procedural knowledge to isomorphic or novel problem-solving situations (i.e., near or far transfer). Additionally, teacher goals may specify constraints on how much time may be invested in order to achieve a particular learning outcome. Because different teacher goals are not mutually exclusive we use the term configuration of teacher goals to refer to relevant instructional goals in a given situation in the remainder of the paper.

As a consequence of the multiplicity of instructional goals, an instructional design that has been proven useful for achieving one instructional goal, for example, the induction of well-defined problem categories, may be less suited to achieve a different instructional goal such as the development of flexible problem-solving knowledge that easily transfers to novel problems. CLT's narrow focus on schema acquisition as the predominant instructional goal leads to the instructional recommendation to prevent learner activities that are not directly related to the acquisition of problem categories. However, these activities may be useful when the learner has to face more challenging, tasks such as solving far transfer problems.

In this line of reasoning Goldman (1991) criticizes CLT for being too narrow in that it prescribes instructional procedures that are useful for near transfer only. She claims that the "dependent measures concentrate too heavily on learning as defined by the ability to master what is presented" (Goldman, 1991, p. 336). If a broader approach to learning and instruction is taken, different teacher goals (e.g., near and far transfer) have to be considered. As a consequence the relation between instructional design and the resulting pattern of germane and extraneous cognitive load becomes more ambiguous, especially

with regard to "the specification a priori of what is extraneous, or at least less critical, and what is central to the learning task" (Goldman, 1991, p. 336).

As the configuration of teacher goals and the respective criteria for evaluating learning outcomes define the degree to which a specific learner activity imposes germane and extraneous load onto working memory, we propose to integrate the configuration of teacher goals as a theoretical variable into CLT. As a consequence, CLT would result in conditional instructional recommendations of the form: Given the configuration $\underline{X}$ of teacher goals, instructional design $\underline{A}$ will yield a better performance than instructional design $\underline{B}$.

Activities of the learner: From our point of view, even if a configuration of teacher goals has been defined it can still not be determined without ambiguity which pattern of cognitive load will result from a specific instructional design. Learners who are confronted with the same instructional environment (including a proposed learning task) and the same configuration of teacher goals may nevertheless differ with regard to their learner activities. This is because the configuration of learner goals and the processing strategies that are deployed to accomplish these goals only partially depend on instructional design and teacher goal configuration:

Configuration of learner goals: Learners are supposed to adopt the teacher goals conveyed through instruction. However, there may also be substantial differences between learner and teacher goals for at least two reasons. First, learner and teacher goals may differ with regard to goal parameters like the level of aspiration or the goal orientation (e.g., mastery versus performance goals). Second, goals that go beyond the teacher goals conveyed through instruction may be relevant for guiding activities of the

learner. In particular, their goal configuration may include transient goals that emerge during the navigation in instructional environments (cf. Hirashima, Hachiya, Kashihara, & Toyoda, 1997) or goals that are related to prospective tasks (cf. Heise, Gerjets, & Westermann, 1997) as well as to personal interests (cf. research on seductive details, Garner, Gillingham, & White, 1989; Harp & Mayer, 1998). These additional goals suggest that there is not necessarily a direct mapping between the configuration of teacher goals and the configuration of learner goals.

Processing strategies: Furthermore, learners' processing strategies add variability to the relation between instructional design and cognitive load. A strategy for performing a task can be defined as "a procedure or set of procedures for achieving a higher-level goal or task. These procedures do not require conscious awareness to be called a strategy" (Lemaire & Reder, 1999, p. 365). Bisanz and LeFevre (1990) emphasize that the term strategy should be exclusively used if a goal or task can be tackled by means of different procedures. The selection of processing strategies within the constraints provided by a specific instructional design should depend on learners' goal configurations, their levels of expertise (i.e., declarative and procedural knowledge available) and other factors like available processing resources and cost-benefit-ratios for different strategies under specific circumstances (cf. Anderson & Lebiere, 1998; Christensen-Szalanski, 1998). Thus, for a given configuration of learner goals different processing strategies may result - depending on the selection policy - which in turn are associated with a specific pattern of cognitive load.

To summarize, up to now variability with regard to the way in which learners process instructional materials has not been taken seriously into account in CLT. Instead,

learner activities have been taken as a rather stable consequence of a specific instructional design. We propose to analyze learner activities in terms of goals and strategies in order to account for the variability with which to-be-learned materials can be handled. According to our view, a learner who is confronted with a specific instructional design has to decide which goals he or she wants to accomplish during learning and which strategies are to be deployed in order to implement these goals.

Our proposals lead to an augmentation of CLT theory that is displayed in Figure 2. This augmented version of CLT is more complex than the original version, however, this increased complexity allows CLT to be extended to a larger range of instructional settings that are characterized by a high level of learner control (e.g., self-controlled computer-based learning environments). In the next section we substantiate this claim with evidence from hypertext-based instruction.

--- Insert Figure 2 here ---

Evidence from Hypertext-Based Instruction

In the following section we are going to draw upon several findings from our own research. Details of the experiments discussed are reported in Gerjets, Scheiter, and Heise (2002), Gerjets, Scheiter, and Tack (2000), Scheiter, Gerjets, and Heise (2000), and Schorr, Gerjets, Scheiter, and Laouris (in press). Although this research did not initially aim at testing the augmented version of CLT, the findings obtained indicate that - at least in the case of hypertext-based instruction - the pattern of cognitive load resulting from a specific instructional design can be determined only when taking into account the

configuration of teacher and learner goals as well as the processing strategies deployed by the learner.

Hypertext environments are network-like information structures in which fragments of information are stored in "nodes" that are interconnected by electronic hyperlinks (Conklin, 1987; Rouet & Levonen, 1996). In order to distinguish hypertext structures from conventional text forms, hypertext is often described as nonlinear in contrast to the linear representation and access to information in traditional text. Hypertext is "capable of being explored in different ways, with the different exploration paths producing what are essentially multiple texts for the same topic" (Spiro & Jehng, 1990, p. 166). Thus, the user can select information units and choose the point of time and the pacing and sequence of their presentation according to his or her goals. This adaptivity implies that the same hypertext may serve a multitude of different goals that guide information utilization.

Configurations of Teacher Goals Determine the Pattern of Cognitive Load (Study 1)

In order to demonstrate that configurations of teacher goals determine the resulting pattern of cognitive load it is useful to evaluate instructional designs with regard to different measures of learning outcomes. Based on an instructional manipulation introduced by Quilici and Mayer (1996) we compared elementary school children who either studied structure-emphasizing or surface-emphasizing sets of worked-out examples in order to acquire knowledge on different problem categories in the domain of basic arithmetic (Schorr et al., in press). Subjects used a hypertext-environment that contained 16 worked-out examples that illustrated four different problem categories and which were embedded in four different cover stories. In the surface-emphasizing condition all four

examples that illustrated a particular problem category shared the same cover story so that each problem category was associated with a specific cover story. Conversely, in the structure-emphasizing condition each cover story was used to illustrate each problem category so that no problem category was associated with a specific cover story. In order to measure learning outcomes, 12 test problems were used that belonged to the same problem categories as the instructional examples. Two types of test problems were designed - equivalent and isomorphic problems according to Reed (1999): For each equivalent test problem there was at least one instructional example that shared the same problem category and the same cover story. Conversely, a test problem was classified as isomorphic if its cover story was different from all instructional examples of the same problem category.

The following pattern of results were obtained: First, learners in the surface-emphasizing condition needed less time studying worked-out examples than learners in the structure-emphasizing condition. Second, subjects who studied surface-emphasizing worked-out examples performed better on equivalent test problems than subjects who studied structure-emphasizing worked-out examples whereas this pattern was reversed for the performance on isomorphic problems. That is, for isomorphic problems the structure-emphasizing condition outperformed the surface-emphasizing condition.

From a cognitive-load perspective these results can be interpreted as follows. Longer learning times in the structure-emphasizing condition indicate that this condition elicits more demanding cognitive processes of identifying structural similarities between examples that differ with regard to their cover stories. These processes may be related to abstraction and schema construction and are not elicited in the surface-emphasizing

condition where cover stories are held constant within problem categories. These cognitive processes of abstraction impose additional cognitive load onto the learner which can, however, only be judged as being germane or extraneous in the light of a specific configuration of teacher goals. If the goal of instruction is to learn very fast how to solve problems equivalent to the instructional examples these additional processes impose extra load onto the learner that is unnecessary or even harmful to accomplish this specific goal of instruction, meaning it is extraneous cognitive load. If, however, the goal of instruction is to solve isomorphic transfer problems these additional processes are critical in order to ensure a good performance, meaning they impose germane cognitive load.

To put it more generally: This type of cross-interaction between instructional-design conditions and different measures of learning outcomes cannot be explained by CLT without augmentations - like distinguishing different configurations of teacher goals - as proposed in our extended model.

Configurations of Learner Goals Determine the Pattern of Cognitive Load (Study 2)

One way of demonstrating that configurations of learner goals determine the resulting pattern of cognitive load is to manipulate learners' goal configuration during the interaction with a learning environment while keeping the goal of instruction constant. In order to investigate the impact of learners' goal configuration on extraneous and germane cognitive load we conducted a hypertext-based experiment where task difficulty and presence of a prospective second task were manipulated (Gerjets et al., 2002; Scheiter et al., 2000). As a starting point, all subjects received three word problems to solve from the domain of combinatorics. During problem solving they could browse an example-based

hypertext environment that contained all information necessary to solve the word problems (i.e., information on problem categories, structural task features, and formulas needed). Additionally, task-irrelevant but interesting information pages which were related to the cover stories of the instructional examples (i.e., topics related to attractiveness and mate choice) could be retrieved by the learner. Processing these additional information pages should result in extraneous cognitive load with regard to the given goal of instruction, i.e., solving word problems. On the contrary, processing the information pages necessary to solve the word problems should result in germane cognitive load. Subjects were instructed to work as fast and as accurately as possible and could decide by themselves which information pages to retrieve.

In order to manipulate <u>task difficulty</u> subjects either received easy or difficult word problems at the beginning of the experiment. Easy problems should be associated with low levels of intrinsic cognitive load whereas difficult word problems should impose high levels of intrinsic cognitive load.

As a second independent variable we manipulated learners' goal configuration by inducing a <u>prospective second task</u>. Subjects without a prospective second task had to solve only the three word problems whereas subjects in the condition with a prospective second task were additionally informed that they would have to work on a second task within the same hypertext environment after having finished the mathematical problem-solving task. This second task consisted of answering three questions about attractiveness and mate choice that were likewise presented briefly at the beginning of the experiment in this condition. The answers to these questions could be found in the additional information pages related to the cover stories of the instructional examples. Subjects were

instructed to work on the problem-solving task first and to postpone thinking about the question-answering task until they had finished the word problems. They were assured that they would have enough time afterwards to browse the hypertext environment for information relevant to this second task.

We assumed that the announcement of a to-be-postponed second task might change learners' goal configuration. That is, although the conditions with and without a prospective second task were equivalent with regard to the learning environment and the goal of instruction announced to the learner (i.e., solving the three mathematical word problems), we expected differences in extraneous cognitive load and therefore in problem-solving performance between these conditions. These differences are supposed to be due to learners' goal configuration during their interaction with the learning environment. The fact that the prospective second task is part of learners' goal configuration might induce goal competition if information relevant to the second task is available in the learning environment. Processing this information might result in extraneous cognitive load and cause performance impairments with respect to the goal of instruction. Furthermore, from a CLT-perspective these effects of a prospective second task were expected to be a function of the current task difficulty: Extraneous cognitive load should be especially harmful for high levels of intrinsic cognitive load, i.e., for difficult problem-solving tasks, whereas there should be a smaller effect in the case of less demanding problem-solving tasks.

The results showed that the presence of a prospective second task indeed impaired problem-solving performance, which yields evidence for the importance of learners' goal configuration as a determining factor for the resulting pattern of germane and extraneous

cognitive load. Additionally, performance impairments due to a prospective second task depended on the difficulty of the problem-solving task. However, the resulting pattern of difficulty-related performance impairments was just the opposite to what was expected under a CLT perspective: For easy word problems, the presence of a prospective second task increased the number of problem-solving errors whereas for difficult word problems there were no differences with regard to problem-solving performance due to the prospective second task.

Although these findings (as well as previous evidence for this pattern of difficulty-related performance impairments due to goal competition, Heise et al., 1997) contradict the predictions derived from CLT, the pattern of results is compatible with predictions derived from theories of action control that postulate a difficulty-related effort investment (cf. Heise, Gerjets, & Westermann, 1994). These theories assume that an enhanced task difficulty leads to an increase in effort invested into the current task which in turn becomes less vulnerable to distractional effects. In order to be able to account for difficulty-related performance impairments in CLT the theory has to be augmented by assumptions on how cognitive resources are allocated to different learner goals (effort allocation). Up to now CLT seems to assume that there is a single learning goal and that all cognitive resources are devoted to this goal to accommodate its task demands. There may, however, be situations where learners avoid investing all of their available cognitive resources in task accomplishment because they possess more complex goal configurations and try to accomplish different goals at the same time.

In order to account for our experimental findings we suggest augmenting CLT by a first-come-first-serve principle of working-memory allocation: Learners working on easy

word problems should be characterized by low initial levels of intrinsic cognitive load and thus have remaining working memory resources at their disposal. These spare resources can be claimed by either extraneous or germane cognitive load during the course of learning and problem solving. Subjects in the conditions without a prospective second task may use these resources to implement rather sophisticated germane processing strategies. Conversely, subjects in the conditions with a prospective second task are presented with information related to their to-be-postponed task that may impose extraneous cognitive load and that prevents subjects from using sophisticated processing strategies for the learning task. This can account for the shallow example-processing strategies and the performance impairments observed in this condition. However, subjects working on difficult word problems should be characterized by high initial levels of intrinsic cognitive load and thus may not have enough working memory resources available for either implementing germane sophisticated processing strategies or for being distracted.

It is important to note that this first-come-first-serve principle of working-memory allocation is not part of CLT but rather an additional assumption that is tied to the issue of learners' goal configurations and their impact on the pattern of cognitive load. Without these augmentations concerning configurations of learner goals and effort allocation findings on difficulty-related performance impairments due to the presence of a prospective second task are difficult to explain by CLT.

Processing Strategies Determine Pattern of Cognitive Load (Studies 3 & 4)

In the preceding sections it has been argued that configurations of teacher goals and learner goals are important variables that determine the pattern of cognitive load resulting

from a specific instructional design. In this section we will discuss evidence showing that the pattern of cognitive load is additionally determined by the strategies of information processing deployed by learners when interacting with a specific instructional design. In CLT it is usually assumed that a specific instructional design elicits or induces a specific type of learner activity. No variability of learner activities as a reaction towards a specific instructional design is expected, thus yielding a rather deterministic relation between instructional design and cognitive load pattern. We are going to review two studies from our own hypertext-based research in order to show that processing strategies may act as important moderators between instructional design and cognitive load - especially in self-controlled learning situations. In these studies we compared different instructional designs and at the same time different strategies of using the information provided in these designs yielding that processing strategies may be better predictors of learning outcomes than are features of the learning environments.

Provision versus utilization of worked-out examples (study 3)

Research over the last 15 years in the domain of learning and problem solving has demonstrated that worked-out examples play an important role in knowledge acquisition (cf. Atkinson, Derry, Renkl, & Wortham, 2000). Although many studies have focused on contrasting the exposure to worked-out examples with alternative instructional devices - like practice problems or abstract instruction - there is also work demonstrating that students' strategies of processing worked-out examples are a critical factor with regard to learning outcome. That is, the mere availability of instructional examples is not sufficient to guarantee the acquisition of schemas that are helpful for later problem solving. Rather,

a profitable utilization of worked-out examples has to be ensured, which may comprise example comparisons and example elaborations.

Example comparisons: Learners have to compare different examples in order to notice structural features that differ among problem categories and that are shared by all problems within a category. Contrasting examples within and among problem categories with regard to their differences and similarities may allow the learner to identify the relevant features of worked-out examples and to avoid confusions by examples' surface features (Cummins, 1992; Quilici & Mayer, 1996).

Example elaborations: Learners have to avoid shallow and frugal example processing that may result from illusions of understanding when learning from worked-out examples (Renkl, 1999). Instead, learners have to make inferences about the structure and solution of worked-out examples that go beyond the information presented in the example (e.g. by relating examples to more abstract information; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Pirolli & Recker, 1994; Renkl, 1997).

Several suggestions have been made how to design example-based instructional settings in order to foster a profitable utilization of worked-out examples, including structuring examples according to their subgoals (Catrambone, 1998), presenting multiple examples with different surface features (Quilici & Mayer, 1996), or presenting incomplete examples that have to be completed by learners (Van Merrienboer & de Croock, 1992).

The aspect of adopting suitable strategies of example utilization gains increasing importance the more the control of the learning process is left up to the learner. In order to determine the relative impact of example-processing strategies and instructional design

in the context of self-controlled learning we conducted a hypertext-based study in the domain of combinatorics (Gerjets et al., 2000). On the one hand, it can be expected that hypertext-environments are especially suited to foster profitable processes of comparing examples within and among problem categories and of relating examples to abstract information. This should be the case because the linking capabilities of nonlinear hypertext allow the learner to flexibly select examples and abstract information pages and to determine the sequence of information presentation. On the other hand, learning with nonlinear hypertext may impose additional extraneous load onto the learner due to the decisions necessary for selecting and sequencing information (Niederhauser et al., 2000).

In the hypertext environment used for experimentation a short introduction to the domain of combinatorics was first presented and subjects were instructed that they would have to solve three probability word problems following a self-paced learning phase. In this learning phase subjects could at least retrieve abstract explanations on six problem categories (with their associated formulas). In the test phase instructional information of the learning phase was no longer available.

As a first independent variable the availability of worked-out examples that illustrated the abstract information on the problem categories and their associated solution procedure during the learning phase was manipulated. Subjects had the opportunity to either receive no worked-out examples, one worked-out example or three worked-out examples with different surface features for each problem category. All examples in the one-example condition were couched in the same cover story. As a second independent variable subjects with low and high domain-specific prior knowledge were distinguished by means of a multiple-choice questionnaire.

The results showed that prior knowledge but not instructional design had a significant impact on later problem-solving performance, i.e., subjects did not differ in performance as a function of whether they could retrieve zero, one or three examples. Thus, at first sight it seems that the instructional examples used in this learning environment were not helpful to foster learning outcomes. However, although the mere provision of one or three examples was obviously not sufficient to improve learning, more detailed analyses of example-processing strategies revealed that mindfully processing these examples was strongly predictive for problem-solving performance. In particular, subjects who processed each example more than once in the one-example condition and subjects who retrieved more than one example per problem category in the three-examples condition showed better performance than subjects who displayed a less intensive example-processing behavior. These two example-processing strategies could be demonstrated to be equally effective in improving performance. There was no relation between example- processing strategies and prior knowledge.

One implication of our findings that has straightforward consequences for CLT is that learners' strategies of using instructional environments may be more important predictors of learning outcomes than instructional design itself. Learners provided with a superior instructional environment (e.g., with multiple worked-out examples) may perform better (by increasing germane cognitive load) or even worse (by suffering from extraneous cognitive load) compared to learners provided with a more inferior instructional environment (e.g., without worked-out examples). Which outcome can be expected depends on whether learners make use of the opportunities to engage in germane processing provided by the instructional design (e.g., by comparing examples

within and between problem categories) or not. In case they do not take a chance on these hypertext capabilities the disadvantages of additional control demands for handling the enriched instructional environment may outweigh the benefits (e.g., decisions related to the selection and sequencing of information pages). These additional demands mainly increase extraneous cognitive load and therefore impair schema acquisition.

<u>Strategic adaptation to time pressure (study 4)</u>

The aforementioned study demonstrates that improving instructional design (e.g., by providing multiple examples) does not automatically result in improved performance unless it is accompanied by profitable strategies of information utilization. Moreover, as the following study indicates, providing unfavorable instructional conditions from a CLT-perspective - such as time pressure - can be rather successfully compensated for by strategic adaptations.

In order to study the effects of time pressure on performance we compared the six aforementioned instructional conditions of study 3 (prior knowledge x number of worked-out examples per problem category) with six equivalent conditions where subjects' learning time was severely restricted to about 60% of the mean learning duration in the respective condition without temporal limitations (Gerjets et al., 2000). During problem solving there were no time limits. From a CLT-perspective it can be postulated that time pressure mainly decreases germane cognitive load by hindering learners from engaging in elaborate processing strategies that make use of helpful additional instructional materials like worked-out examples. The theory would predict that subjects learning under time pressure need to skip instructional materials that would under normal circumstances allow for a mindful cognitive processing with a high degree

of germane cognitive load. Skipping these materials under time pressure should therefore result in a reduced learning outcome.

Contrary to the prediction above, our findings showed that even a strong reduction of learning time did not necessarily impede learning outcomes. This indicates that subjects may have been able to strategically adapt to time pressure. Analyzing strategies of information utilization under time pressure demonstrated that learners under time pressure refrained from elaborate example processing and invested their time in processing abstract information without showing deterioration in performance. From a CLT-perspective there are two possible explanations to account for these results: Learners under time pressure either process abstract information more thoroughly (i.e., allocate more cognitive resources on processing this information) and thereby increase germane cognitive load. Or it may be that they reduce extraneous cognitive load by ignoring most of the additional information provided in the hypertext environment and thereby avoiding extraneous decision processes. Thus, although time pressure should be a very unfavorable instructional condition from a cognitive-load perspective, strategic adaptation resulting in an improved pattern of cognitive load may enable learners to cope even with strong time pressure.

Summary

Cognitive Load Theory provides a useful framework for analyzing instructional design features with regard to their suitability for supporting processes of schema construction and automation. This analysis is based on determining the pattern of intrinsic, germane, and extraneous cognitive load associated with a specific instructional design at a particular level of expertise. However, in order to extend the range of

successful applications of CLT to instructional settings that are characterized by a high level of learner control (e.g., self-controlled learning in hypertext-environments) we recommend that CLT be augmented by several variables that moderate the relation between instructional design and the resulting pattern of cognitive load. We outlined an extended CLT-model that specifies these variables and their interrelations. Evidence from our own hypertext-based research indicates that configurations of teacher goals, configurations of learner goals, and learners' processing strategies may be important moderating variables that should be incorporated into CLT.

References

Anderson, J. R., & Lebiere, C. (1998). The atomic components of thought. Hillsdale, NJ: Erlbaum.

Atkinson, R. K., Derry, S. J., Renkl, A., & Wortham, D. (2000). Learning from examples: Instructional principles from the worked examples research. Review of Educational Psychology, 70, 181-214.

Baddeley, A. (1992). Working memory. Science, 255, 556-559.

Bisanz, J., & LeFevre, J. (1990). Strategic and nonstrategic processing in the development of mathematical cognition. In D. F. Bjorklund (Ed.), Children's strategies: Contemporary views of cognitive development (pp. 213-244). Hillsdale, NJ: Erlbaum.

Catrambone, R. (1998). The subgoal learning model: Creating better examples so that students can solve novel problems. Journal of Experimental Psychology: General, 127, 355-376.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. Cognition and Instruction, 8, 293-332.

Chi, M. T. H., Bassok, M., Lewis, M., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. Cognitive Science, 13, 145-182.

Christensen-Szalanski, J. J. J. (1998). Problem-solving strategies: A selection mechanism, some implications, and some data. In L. R. Beach (Ed.), Image theory: Theoretical and empirical foundations (pp. 159-175). Mahwah, NJ: Erlbaum.

Conklin, J. (1987). Hypertext: An introduction and survey. IEEE Computer, 20, 17-41.

Cooper, G., & Sweller, J. (1987). Effects of schema acquisition and rule automation

on mathematical problem-solving transfer. Journal of Educational Psychology, 79, 347-

362.

Cummins, D. D. (1992). Role of analogical reasoning in the induction of problem

categories. Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,

1103-1124.

Garner, R., Gillingham, M. G., & White, C. S. (1989). Effects of "seductive details"

on macroprocessing and microprocessing in adults and children. Cognition and

Instruction, 6, 41-77.

Gerjets, P., Scheiter, K. & Heise, E. (2002). Distraction in hypertext environments:

Effects of goal competition and task difficulty on strategies of information utilization and

performance. Manuscript submitted for publication.

Gerjets, P., Scheiter, K., & Tack, W. H. (2000). Resource-adaptive selection of

strategies in learning from worked-out examples. In L. R. Gleitman & A. K. Joshi (Eds.),

Proceedings of the 22nd Annual Conference of the Cognitive Science Society (pp. 166-

171). Mahwah, NJ: Erlbaum.

Goldman, S. R. (1991). On the derivation of instructional applications from

cognitive theories: Commentary on Chandler and Sweller. Cognition and Instruction, 8,

333-342.

Harp, S. F., & Mayer, R. E. (1998). How do seductive details do their damage: A

theory of cognitive interest in science learning. Journal of Educational Psychology, 90,

414-434.

Heise, E., Gerjets, P., & Westermann, R. (1994). Idealized action phases: A concise Rubicon-theory. In M. Kuokkanen (Ed.), <u>Structuralism, idealization and approximation</u> (pp. 141-158). Amsterdam: Rodopi.

Heise, E., Gerjets, P., & Westermann, R. (1997). The influence of competing intentions on action performance: Efficiency impairment and volitional protection in tasks of varying difficulty. <u>Acta Psychologica, 97</u>, 167-182.

Hirashima, T., Hachiya, K., Kashihara, A., & Toyoda, J. (1997). Information filtering using user's context on browsing in hypertext. <u>User Modeling and User-Adapted Interaction, 7</u>, 239-256.

Lemaire, P., & Reder, L. (1999). What affects strategy selection in arithmetic? The example of parity and five effects on product verification. <u>Memory & Cognition, 27</u>, 364-382.

Niederhauser, D. S., Reynolds, R. E., Salmen, D. J., & Skolmoski, P. (2000). The influence of cognitive load on learning from hypertext. <u>Journal of Educational Computing Research, 23</u>, 237-255.

Pirolli, P., & Recker, M. (1994). Learning strategies and transfer in the domain of programming. <u>Cognition and Instruction, 12</u>, 235-275.

Quilici, J. L., & Mayer, R. E. (1996). Role of examples in how students learn to categorize statistics word problems. <u>Journal of Educational Psychology, 88</u>, 144-161.

Reed, S. K. (1999). <u>Word problems</u>. Mahwah, NJ: Erlbaum.

Renkl, A. (1997). Learning from worked-out examples: A study on individual differences. <u>Cognitive Science, 21</u>, 1-29.

Renkl, A. (1999). Learning mathematics from worked-out examples: Analyzing and fostering self-explanations. European Journal of Psychology of Education, 14, 477-488.

Rouet, J.-F., & Levonen, J. J. (1996). Studying and learning with hypertext: Empirical studies and their implications. In J.-F. Rouet, J. J. Levonen, A. Dillon, & R. J. Spiro (Eds.), Hypertext and cognition (pp. 9-23). Mahwah, NJ: Erlbaum.

Scheiter, K., Gerjets, P., & Heise, E. (2000). Hypertext navigation and conflicting goal intentions: Using log files to study distraction and volitional protection in learning and problem solving. In L. R. Gleitman & A. K. Joshi (Eds.), Proceedings of the 22nd Annual Conference of the Cognitive Science Society (pp. 441-446). Mahwah, NJ: Erlbaum.

Schorr, T., Gerjets, P, Scheiter, K., & Laouris, Y. (in press). Designing sets of instructional examples to accomplish different goals of instruction. In W. D. Gray & C. D. Schunn (Eds.), Proceedings of the 24rd Annual Conference of the Cognitive Science Society. Mahwah, NJ: Erlbaum.

Spiro, R. J., & Jehng, J.-C. (1990). Cognitive Flexibility and Hypertext: Theory and technology for the nonlinear and multidimensional traversal of complex subject matter. In D. Nix & R. J. Spiro (Eds.), Cognition, education, and multimedia (pp. 163-205). Hillsdale, NJ: Erlbaum.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. Learning and Instruction, 4, 295-312.

Sweller, J., van Merrienboer, J. G., & Paas, F. (1998). Cognitive architecture and instructional design. Educational Psychology Review, 10, 251-296.

VanLehn, K. (1996). Cognitive skill acquisition. <u>Annual Review of Psychology,</u> <u>47</u>, 513-539.

Van Merrienboer, J. G., & De Croock, M. (1992). Strategies for computer-based programming instruction: Program completion vs. program generation. <u>Journal of</u> <u>Educational Computing Research, 8</u>, 365-394.

Author Note

Figure Captions

Figure 1. Pivotal assumptions of CLT

Figure 2. Goals and strategies as moderators between instructional design and cognitive

load

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┌─────────────┐     ┌──────────┐     ┌─────────────┐
│Instructional│ ──▶ │ Learner  │ ──▶ │ Extraneous/ │
│ Design      │     │ Activity │     │ Germane     │
└─────────────┘     └──────────┘     │ Cognitive   │
                                     │ Load        │ ──▶  ┌──────────┐
                                     └─────────────┘      │ Learning │
                                                          │ Outcome  │
┌─────────────┐                      ┌─────────────┐      └──────────┘
│ Expertise   │ ─────────────────▶   │ Intrinsic   │ ──▶
└─────────────┘                      │ Cognitive   │
┌─────────────┐                      │ Load        │
│ Relational  │ ─────────────────▶   └─────────────┘
│ Complexity  │
└─────────────┘
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Configuration of Teacher Goals

Learner Activities

Instructional Design

Configuration of Learner Goals

Processing Strategies

Extraneous/ Germane Cognitive Load

Learning Outcome

Expertise

Relational Complexity

Intrinsic Cognitive Load