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Direct Measurement of Cognitive Load in Multimedia Learning

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Cognitive load theory (CLT) is gaining increasing importance in the design and evaluation of instruction, both traditional and technology based. Although it is well understood as a theoretical construct, the measurement of cognitive load induced by instructional materials in general, and by multimedia instruction in particular, mainly relies on methods that are either indirect, subjective, or both. Integrating aspects of CLT, working memory research, and cognitive theories of multimedia learning, we describe the conceptual basis and practical implementation of a dual-task approach to the direct measurement of cognitive load in multimedia learning. This computer-based instrument provides a direct and objective measure that overcomes many of the shortcomings of other indirect and subjective methods that will enable researchers to validate empirically theoretical predictions of CLT.

Research on cognitive load has been the focus of active investigation for the past 30 years (Chandler & Sweller, 1991; Johnson-Laird & Wason, 1970; Sweller, 1999). Researchers have identified different sources that contribute to cognitive load, formulated principles of instructional design that are based on cognitive load theory (CLT), and learned how to design instructional strategies and activities that reduce certain types of load (Chandler & Sweller, 1991; Mayer, 2001; Sweller, 1999; Sweller, van Merriënboer, & Paas, 1998). Studies have also shown that it is a learner's prior knowledge (i.e., the complexity of existing schemas for a particular subject matter) that determines what level of cognitive load the individual will experience (Kalyuga, Ayres, Chandler, & Sweller, 2003). Recently, CLT has become one of the fundamental theories used to describe the cognitive processes in learning with new technologies, such as multimedia environments or web-based instruction (Mayer, 2001; Niegemann, 2001). Because it provides a theory-based approach to the prediction of the effectiveness of multimedia- and web-based learning, CLT is increasingly used to inform the instructional design of such learning environments (Brünken & Leutner, 2001; Plass & Salisbury, in press). Yet, despite 3 decades of research, its key concept—cognitive load—has largely eluded our attempts of direct measurement in authentic learning situations. Although some indirect methods have been used to assess cognitive load, including, for example, questionnaires eliciting self-reports of invested mental effort (Paas & van Merriënboer, 1993), a more reliable and valid method is needed to allow us to validate empirically theoretical predictions of CLT. In this article, we propose such a method of directly assessing cognitive load that is based on the dual-task methodology.

THEORETICAL BACKGROUND

Cognitive Load Theory and Instructional Design

Based on different sources for cognitive load, Sweller (1999) distinguished three types of load: one type that is attributed to

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the inherent structure and complexity of the instructional materials and cannot be influenced by the instructional designer, and two types that are imposed by the requirements of the instruction and can, therefore, be manipulated by the instructional designer.

The cognitive load caused by the structure and complexity of the material is called *intrinsic cognitive load.* The complexity of any given content depends on the level of item or component interactivity of the material, that is, the amount of informational units a learner needs to hold in working memory to comprehend the information (Pollock, Chandler, & Sweller, 2002). Cognitive load imposed by the format and manner in which information is presented and by the working memory requirements of the instructional activities is referred to as *extraneous cognitive load,* a term that highlights the fact that this load is a form of overhead that does not contribute to an understanding of the materials. Finally, the load induced by learners' efforts to process and comprehend the material is called *germane cognitive load* (Gerjets & Scheiter, 2003; Renkl & Atkinson, 2003).

Both extraneous and germane cognitive load can be manipulated by the instructional design of the learning material. Among the instructional strategies that have been found to reduce extraneous cognitive load and optimize germane cognitive load are worked examples (Kalyuga, Chandler, Tuovinen, & Sweller, 2001); goal-free activities (Sweller, 1999); strategies of imagining (Cooper, Tindall-Ford, Chandler, & Sweller, 2001); and activities that are designed based on the completion effect (van Merriënboer, Schuurman, de Croock, & Paas, 2002), modality effect (Brünken & Leutner, 2001; Mayer & Moreno, 2003; Sweller, 1999), and redundancy effect (Sweller, 1999).

The goal of the design of instruction is to optimize cognitive load for a particular learner. Because the intrinsic load of a given instructional material cannot be manipulated, this involves the design of instructional strategies that induce low-extraneous and optimal germane load, a task that requires an understanding of the architecture and limitations of working memory.

Cognitive Load and Working Memory

CLT is based on several assumptions regarding human cognitive architecture: the assumption of a virtually unlimited capacity of long-term memory, schema theory of mental representations of knowledge (Chi, Glaser, & Rees, 1982; Larkin, McDermott, Simon, & Simon, 1980), and limited-processing capacity assumption for working memory (Miller, 1956). Current models describe working memory as mechanisms and processes that control, regulate, and actively maintain task-relevant information (Miyake & Shah, 1999). For example, the well-known Baddeley (1986) model of working memory assumes the existence of a central executive that coordinates two slave systems, a visuospatial sketchpad for visuospatial information such as written texts or pictures and a phonological loop for phonological information such as spoken text or music (Baddeley, 1986; Baddeley & Logie, 1999). It is also assumed that both slave systems are limited in capacity and independent from one another in that the processing capacities of one system cannot compensate for lack of capacity in the other.

For each of the two working memory subsystems the total amount of cognitive load for a particular individual under particular conditions is defined as the sum of intrinsic, extraneous, and germane load induced by the instructional materials. Therefore, a high-cognitive load can be a result of a high-intrinsic cognitive load (i.e., a result of the nature of the instructional content itself). It can, however, also be a result of a high-extraneous or germane cognitive load (i.e., a result of activities performed on the materials that result in a high-memory load). In other words, the same learning material can induce different amounts of memory load when different instructional strategies and designs are used for its presentation, because the different cognitive tasks required by these strategies and designs are likely to result in varying amounts of extraneous and germane load.

If the difference between the total cognitive load and the processing capacity of the visual or auditory working memory approaches zero, then the learner experiences a high-cognitive load or overload. It is the amount of this difference, which, for the purpose of this article, we call *free cognitive resources,* that we use as a basis for our method of direct measurement of cognitive load during multimedia learning.

Cognitive Load and Multimedia Learning

The foundation and implications of CLT can be especially well investigated in the context of multimedia learning, because the use of this technology as instructional medium involves perceiving and processing information in different presentation modes and sensory modalities. A process theory that supplements CLT in the description of the cognitive processes in multimedia learning was introduced by Mayer (2001) as the generative theory of multimedia learning.

Two of the principle foundations of this theory of multimedia learning are the *dual-coding assumption* and the *dual-channel assumption.* The dual-coding assumption refers to the presentation mode of the information and posits that verbal material (e.g., written or spoken text) and pictorial material (e.g., pictures, graphics, or maps) are processed and mentally represented in separate but interconnected systems, an assumption taken from dual-coding theory (Paivio, 1986). The dual-channel assumption refers to the sensory modality of information perception and proposes that visual information (e.g., written text) and auditory information (e.g., spoken text) are processed in different systems that correspond to the visuospatial and phonological subsystems in Baddeley's (1986) working memory model.

The generative theory of multimedia learning combines these two assumptions with a generative approach to learning (Wittrock, 1974, 1990) by stating that learners actively select relevant visual and verbal information from the learning material and organize them in visual and verbal working memory, respectively, by building associative connections between them. Learners then integrate the mental representations as well as prior knowledge by building referential connections (Mayer, 2001). These processes require cognitive resources and are executed within the limits of working memory capacity (Mayer, 2001; Plass, Chun, Mayer, & Leutner, in press).

Several principles have been identified that describe the impact of the instructional design on learning with multimedia. Based on CLT, they describe effects that can be grouped into three categories: (a) principles that reduce extraneous load by enhancing information integration and schema construction (multimedia effect, split-attention effect, and contiguity effect; Brünken, Steinbacher, Schnotz, & Leutner, 2001; Mayer, 2001), (b) principles related to the individual learner's amount of available capacity (individual differences effect and expertise reversal effect; Plass, Chun, Mayer, & Leutner, 1998, in press; Kalyuga et al., 2003) and (c) principles that are concerned with optimizing the use of available capacity for information processing (modality effect, redundancy principle, and coherence principle; Brünken & Leutner, 2001; Mayer, 2001; Mayer & Moreno, 1998).

The *modality effect* may best illustrate how these principles allow for the design of multimedia instruction that enhances learning outcomes. Focusing on the sensory modality of information, this principle states that knowledge acquisition is better facilitated by materials presented in a format that simultaneously uses the auditory and the visual sensory modality than by a format that uses only the visual modality (Mayer, 2001). Consider, for example, a multimedia episode that describes the functioning of the human heart. Using a graphical representation depicting the heart, the circulation of the blood is explained using words. In one variant of the system, these words are presented as visual information (i.e., as text on the computer screen). Another variant does not include on-screen text but presents the words in a narration instead. The modality effect predicts that learners who receive the picture-and-narration variant will comprehend the materials better than those who receive the picture-and-text variant, because the former uses the visual (picture) as well as the auditory (narration) sensory modality, whereas the latter involves only the visual modality (picture and on-screen text). This effect has been replicated in several studies for different types of print- and computer-based materials and with different types of learners (Brünken & Leutner, 2001; Mayer, 2001; Mayer & Moreno, 1998; Mousavi, Low, & Sweller, 1995; Tindall-Ford, Chandler, & Sweller, 1997).

Using CLT, the modality effect can be explained by describing the memory load condition for each of the treatments. The picture-and-text variant induces a higher load in visual working memory, because both types of information are processed in this system. In comparison, the picture-and-narration variant induces a lower amount of load in visual working memory, because auditory and visual information are each processed in their respective system; thus, the total load induced by this variant of the instructional materials is distributed among the visual and the auditory system. Indeed, from experimental investigations we know that learning is increased by a multimodal (picture and narration) presentation format compared to a single-modal (picture and on-screen text) format. However, the amount of actual cognitive load induced by these different presentation formats, which could explain this effect, has not been measured in these studies. In fact, recent research on multimedia learning routinely uses cognitive load as a theoretical rationale to explain differences in learning outcomes but does not actually assess the amount of cognitive load imposed on the learners (Brünken, Steinbacher, Plass, & Leutner, 2002). This leads us to the central problem addressed in this article—the measurement of cognitive load in multimedia learning.

MEASUREMENT OF COGNITIVE LOAD

Current Approaches

Cognitive load can be treated as a theoretical construct, describing the internal processes of information processing that cannot be observed directly. However, to use this concept to inform the design of instruction, valid and reliable instruments assessing cognitive load are needed.

The various methods of assessing cognitive load that are currently available can be classified along two dimensions, *objectivity* (subjective or objective) and *causal relation* (direct or indirect). The objectivity dimension describes whether the method uses subjective, self-reported data or objective observations of behavior, physiological conditions, or performance. The causal relation dimension classifies methods based on the type of relation of the phenomenon observed by the measure and the actual attribute of interest (Table 1). For example, a direct link exists between cognitive load and the

TABLE 1
Classification of Methods for Measuring Cognitive Load Based on Objectivity and Causal Relationship

	Causal Relationship	
Objectivity	*Indirect*	*Direct*
Subjective	Self-reported invested mental effort	Self-reported stress level
		Self-reported difficulty of materials
Objective	Physiological measures	Brain activity measures (e.g., fMRI)
	Behavioral measures	Dual-task performance
	Learning outcome measures	

difficulty of the learning materials, because this difficulty is a direct result of the intrinsic and extraneous load of the materials. An indirect link exists between navigation errors and cognitive load, as frequent errors may be caused by an incomplete mental model of the learning environment, which itself may be a result of high-cognitive load. We use the criteria of objectivity and causal relation to discuss the different measures of cognitive load currently available.

Indirect, subjective measures. Paas, van Merriënboer, and Adam (1994) introduced a subjective, indirect measure of cognitive load that, based on early work by Borg, Bratfisch, and Dornic (1971), uses posttreatment questionnaires in which learners are asked to report the amount of mental effort invested in understanding the learning materials. Although this technique, which is frequently used in current cognitive load research (see Paas, Tuovinen, Tabbers, & Van Gerven, 2003), appears to be able to assess the subjective perception of invested effort reliably, it remains unclear how this mental effort relates to actual cognitive load. As other research has shown, a low amount of invested effort could be a result of low-cognitive load or, arguably, of such a high load that the learner decreased the mental effort expended on comprehending the materials (Reed, Burton, & Kelly, 1985)—an issue that applies to other measures of cognitive load as well.

Direct, subjective measures. A second subjective measure used, for example, by Kalyuga, Chandler, and Sweller (1999), is the *rating of the difficulty of the materials*, which relates directly to the cognitive load imposed. Kalyuga et al. reported a high sensitivity of these scales in identifying differences in training strategies, but these differences could potentially also have been caused by task difficulty, individual competency levels of the learners, or different attentional processes.

Indirect, objective measures. The most common method of investigating cognitive load effects is to analyze *performance outcome measures*, which, in the area of multimedia learning, are usually knowledge acquisition scores. Outcome measures of the learning task are objective because they measure performance. They are indirect because they depend on processes of information storage and retrieval that may be affected by cognitive load.

The typical design of research studies using this approach compares two or more different variants of multimedia instruction of the same material. The amount of intrinsic load induced by each of the variants is presumed equal because the informational contents of these materials are identical. It is, therefore, assumed that the more knowledge the learners acquire, the less extraneous load is induced by the instruction. However, such an interpretation is challenged by studies that found that these differences in learning outcomes are not only caused by the different types of multimedia instructions, but they can also be caused by the measurement method (e.g., the type of tests employed in such investigations; Brünken et al., 2001; Mayer, 2001). In addition, empirical studies on individual differences consistently show that learning outcomes are highly affected by learners' traits (Mayer, 2001; Plass et al., 1998, in press).

The analysis of behavioral *patterns or physiological conditions and functions* and their correlation with the learning process represents another form of indirect, objective cognitive load measurement. For example, learners' time-on-task can be seen as an indicator for different load levels: The different amounts of time that subjects spent learning with different variants of multimedia instruction could be a result of different amounts of load induced by these variants (Brünken & Leutner, 2001; Brünken et al., 2001). In the hypermedia learning literature, navigation behavior, navigation errors, and orientation problems such as *lost-in-hyperspace* are used as indicators of cognitive load (Astleitner & Leutner, 1996). Another method, used in experimental psychology and in cognitive load research, is eye-tracking analysis (Paas et al., 2003). However, although these behavioral measures are objective, they are only indirectly linked to cognitive load and could, for example, also be a function of factors such as attentional or motivational processes (Brünken et al., 2002).

Physiological measures, such as heart rate (Paas & van Merriënboer, 1994) and pupil dilation (Beatty, 1982) have, similar to behavioral patterns, only an indirect causal link to cognitive load. For example, high-cognitive load may lead to high stress in an individual, which may lead to changes in heart rate—as may the individual's emotional response to the learning materials.

Direct, objective measures. A promising direct method of measuring load that is increasingly gaining importance is the use of *neuroimaging techniques*, such as positron-emission tomography and functional magnetic resonance imaging (fMRI), to measure brain activation during task execution (Smith & Jonides, 1997). Although this method is routinely used to visualize brain region activation in working memory studies involving simple tasks, such as word memorization, sentence comprehension, or visual rotations (Just, Carpenter, Keller, Emery, Zajac, & Thulborn, 2001), it is as of yet inconclusive for the study of complex learning processes, and the connection between memory load and prefrontal cortex activity is not yet fully understood (Braver, Cohen, Nystrom, Jonides, Smith, & Noll, 1997). In addition, the technical complexity of the measurement apparatus and the practical limitations of the duration and frequency of measurements make its use in authentic learning situations difficult. However, once these problems have been overcome, this method may be a potential new approach for the direct, objective measurement of cognitive load in complex learning processes.

Another method of direct, objective measurement of cognitive load uses the *dual-task-paradigm*, which is well known in experimental psychology (e.g., Verwey & Veltman, 1996; Wickens, 1984) and more closely related to cognitive load in working memory research (Baddeley, 1986; Miyake & Shah, 1999). Dual-task analysis is based on the assumption of limited cognitive resources that can be allocated flexibly to different aspects of task solving. If a learner has to perform two tasks simultaneously (e.g., a learning task and a monitoring task), and if both tasks require the same resources in verbal and/or visual working memory, then the available verbal and visual resources have to be distributed between both tasks.

The dual-task approach can be used in two different ways. In one approach, a secondary task is added to a primary task with the intention of inducing memory load. The dependent variable of interest is the performance in the primary task, which should decrease in a dual-task condition compared to a single-task condition (i.e., the primary task alone). A second approach is to use a secondary task for the measurement of the memory load induced by a primary task. Here, the performance in the secondary task is the variable of interest. If different variants of a primary task induce different amounts of memory load, then the performance in the secondary task will vary accordingly.

Dual-Task Measurement of Cognitive Load in Multimedia Learning

Although the dual-task method is the primary approach used in working memory research (i.e., in the study of the executive and maintenance processes involved in holding information in memory for short periods of time; Baddeley & Logie, 1999), it has been utilized only rarely in cognitive load research (Chandler & Sweller, 1996; Marcus, Cooper, & Sweller, 1996; Sweller, 1988) and in the field of multimedia learning (Brünken et al., 2002). This is surprising, because a dual-task approach seems to be particularly promising for the direct measurement of the extraneous cognitive load induced by different variants of multimedia instruction. If the amount of extraneous load induced by a specific learning material depends on the instructional design of the material, as CLT as well as multimedia learning theories predict, then different design variants of the same content should lead to different performances in a secondary task that has to be attended to simultaneously with the primary learning task. The learners' performance in the secondary task can then be used as a direct measure of the cognitive load induced by the multimedia instruction.

Several benefits of the dual-task method of cognitive load assessment make this approach even more attractive. First, the fact that both the multimedia instruction (as primary task) and the secondary task are attended to at the same time makes it possible to measure cognitive load at the very point in time when the load is induced in the learner. Other measures, such as subjective rating scales of mental effort, can only be reasonably applied after the task execution. Second, as we know from working memory research, there are different secondary tasks that are linked to different process steps of information processing, such as perception, preprocessing in one of the slave systems, or information integratio (Baddeley, 1986). These different tasks make it possible to identify in which of the process steps the cognitive load is imposed. Third, the dual-task analysis is usually carried out in within-subjects designs. Measuring the load induced by different design variants of multimedia instruction for the same learner makes the load measurement independent from individual differences, such as abilities, interest, or prior knowledge, that are known to affect learning outcomes in between-subjects designs.

However, there are some methodological and technical challenges that have to be taken into consideration when applying the dual-task approach to cognitive load research in multimedia learning (Lansman & Hunt, 1982; Paas et al.,1994). First, for the secondary task to be a sensitive measure it has to require the same cognitive resources as the primary task; otherwise, secondary task performance will be independent of primary task performance. Second, the performance measure for the secondary task has to be reliable and valid. Third, the secondary task has to be so simple that it does not suppress simultaneous learning processes; otherwise, the secondary task may affect the learning outcome of the primary task, the multimedia instruction, by requiring cognitive resources that are no longer available for learning (Marcus et al., 1996). Because primary task performance is not the variable of interest in this context, this might not be a problem as long as the learning process is not suppressed in general. Finally, the secondary task has to be able to consume flexibly all of the available free cognitive capacity.

A suitable performance measure that fulfills these requirements and has been successfully used in previous working memory research is the measure of reaction time (Verwey & Veltman, 1996; Wickens, 1984). The basic idea for load measurement based on reaction time is that the learner has to react to a specific signal during a very simple continuous monitoring task as soon as possible. Because the monitoring task itself requires only few cognitive resources, it does not suppress the primary task; yet, when a reaction is necessary, the as-soon-as-possible condition consumes all available resources. This design minimizes the interference between the two tasks and maximizes the exhaustion of the free capacity. The performance on the secondary task (i.e., the speed of reaction) is directly related to the amount of free capacity, which itself depends on the amount of capacity required by the primary task. Thus, reaction time in a secondary monitoring task is a valid measure of cognitive load induced by the multimedia instruction serving as primary task.

Experimental Evidence

Experimental evidence for the suitability of dual-task measurement in assessing cognitive load consists of a small number of experimental investigations with textbook instruction, computer-based environments, and multimedia learning environments. For textbook-based research, Marcus et al. (1996) used different forms of simultaneously presented secondary tasks for assessing cognitive load induced by different instructional designs of visual primary tasks. They found secondary task measurements to be related to the load induced by the primary task, under the condition that both tasks required the same cognitive resources. Britton, Glynn, Meyer, and Penland (1982) found statistically significant relations between secondary task performance and knowledge acquisition from differently structured texts that required different amounts of cognitive capacity to process.

In computer-based learning environments, Reed et al. (1985) used a dual-task design to study the effects of writing ability and mode of discourse on cognitive capacity engagement for different computer-based writing tasks with different levels of difficulty. They found that the cognitive engagement of learners increased from the easiest task that induced a low level of cognitive load to the moderately difficult task with a medium level of load, but it actually decreased for the most difficult task that induced the highest levels of load. Chandler and Sweller (1996) reported findings on the usability of secondary tasks in cognitive load research for computer-based learning materials for computer-aided design (CAD) using a secondary task generated by a second computer that was presented on a separate computer screen simultaneously to the CAD program on the first computer. They found secondary task performance to be related to split-attention and redundancy effects in the primary task as well as to element interactivity (i.e., intrinsic load) of the material and showed that secondary task performance decreased in relation to the cognitive load induced by the instructional design of the primary task.

In our own research, we studied the feasibility of the dual-task approach to measure cognitive load in multimedia learning using the modality effect as an example (Brünken et al., 2002). As discussed earlier, the theoretical rationale underlying the modality effect is that the visual-only presentation of textual and pictorial learning materials requires information processing only in the visual subsystem, whereas the audiovisual presentation of the same material can be processed in both the visual and the auditory system. Therefore, more cognitive capacity should be available for processing information in the audiovisual condition, which should result in better learning compared with the visual-only condition.

Two experimental studies were conducted based on these considerations (Brünken et al., 2002) in which a visual secondary reaction time task was added to two different multimedia learning tasks. The first experiment used a multimedia environment on the human cardiovascular system (Brünken & Leutner, 2001); the second experiment involved a multimedia travel guide (Brünken et al., 2001). For each experiment, the multimedia instruction from the previous studies was redesigned to fit an within-subjects design, alternating pages between a visual-only format and an audiovisual format.

The secondary task presented to the learners was a simple visual-monitoring task, requiring learners to react as soon as possible to a color change. For this purpose, a small frame was added to the computer screen, centered above the primary task frame, that displayed the learning materials (see Figure 1). Within this small frame, a single letter was continuously displayed. Occasionally, the letter's color changed from black to red, indicating a response request. After the learners' response (pressing a key on the computer keyboard), the color of the letter reversed to black, and the software recorded the reaction time. The experiments included three experimental conditions for each learner: a single-task condition with the secondary task alone, a dual-task condition with visual-only learning material as primary task, and a dual-task condition with audiovisual learning material. Within each condition, repeated measures of reaction time were taken at random intervals.

The results of these studies clearly showed the feasibility of our dual-task approach. The performance on the secondary task was significantly faster in the single-task condition than in the dual-task conditions, implying that the secondary task is a sensitive measure that indeed requires the same cognitive resources as the primary task. Comparing the two dual-task conditions, the reaction times were, as predicted by CLT, significantly faster for the audiovisual primary task than for the visual-only primary task condition: Effect sizes were .82 in

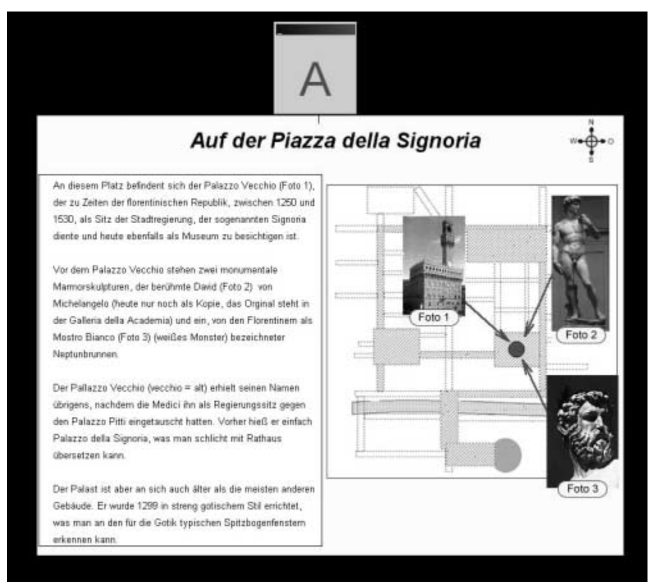

FIGURE 1 Screen shot of the dual-task condition with the secondary task centered on top and the multimedia learning materials of the primary task under it.

Experiment 1 and .75 in Experiment 2, representing a medium to large effect. Perhaps the most impressive result obtained in these experiments, however, was that this effect pattern was found not only by averaging across participants but also for every single participant, without any exceptions (Brünken et al., 2002).

The significance of these experiments is that we were able to show, for the first time in the domain of learning with complex multimedia systems, that the differences in learning outcome found in the modality effect are indeed related to different levels of cognitive load induced by the different presentation formats of the learning material.

DISCUSSION

In this article, we discussed different methods of assessing cognitive load in multimedia learning. We identified direct and indirect performance measures; subjective ratings; and behavioral, physiological, and neuroimaging measures; and we discussed their strengths and shortcomings. We introduced a new direct measure of cognitive load in multimedia learning based on the dual-task paradigm. Our measure uses a continuous visual monitoring task as secondary task, allowing us to measure cognitive load in the visual system. Two experiments demonstrated the feasibility of this approach, as they were able to reproduce the modality effect found in two different multimedia learning environments as a cognitive load effect.

The dual-task method of measuring cognitive load for multimedia learning represents a promising alternative to existing methods. The most important benefit of this method is that it is able to measure cognitive load without relying on subjective self-reported data, indirect performance measures, or behavioral or physiological measures that have only an indirect causal link to cognitive load and that may, therefore, be affected by other factors. Instead, it provides, similar to brain activation measures, a direct way to measure cognitive load. In comparison to other methods, such as neuroimaging techniques, heart rate measures, or eye tracking, the technical apparatus required for this method is minimal and easily implemented.

However, there are some shortcomings associated with the dual-task approach that have to be considered. First, based on the dual-channel assumption, the use of the method depends on the sensory modality of the information. The investigation of acoustical information, for example, would require the use of auditory secondary tasks, which would be expected to reveal the opposite pattern for the modality effect than was found for visual tasks: Reaction times in the audiovisual primary task condition should be comparatively longer than in the visual-only condition because of the higher amount of load in the auditory working memory subsystem. Second, the use of reaction time measures requires within-subjects designs, which have been used less frequently in recent multimedia research than between-subjects designs. However, as research in individual differences has shown, cognitive load varies to a significant degree among different learners. A particular instructional design can cause extraneous load in one learner, whereas the same design can induce germane load in another, which can even change the effect of the instructional design from enhancing to hindering knowledge construction. Within such an individualized view of cognitive load effects, within-subjects designs may not only be an alternative but may indeed offer more appropriate research designs.

Another issue related to this approach is that the secondary task, even if it is designed as a very simple task requiring few resources, may still affect the learning outcomes in the primary task. Future studies should measure both the primary and secondary task performance simultaneously to validate differences in cognitive load and knowledge acquisition caused by different instructional designs within the same experiment.

A more general problem of cognitive load measures was described by Reed et al. (1985), who found a reversal effect in cognitive engagement with increasing difficulty of the materials. For very easy materials, low-cognitive load scores were obtained, and they increased with increasingly difficult tasks. However, when the primary tasks became too difficult, the load scores obtained were again low, this time indicating a cognitive disengagement of the learner. This reversal effect underlines the necessity to assess the prior knowledge of the learners in the particular instructional topic and to match the difficulty of the instructional materials to the level of prior knowledge. From a theoretical perspective, this effect provides motivation to reevaluate the simple additional component model underlying CLT, which may have to be refined to incorporate interactions such as those between intrinsic load, germane load, and learners’ level of experience.

An additional issue, stemming from research on the dual-task approach but relevant to cognitive load theory in general, concerns the relation between cognitive load and attentional processes, which in our view, needs to be examined in more detail. Although cognitive load theory posits that different effects, such as the modality effect or the split-attention effect as well as secondary task performance, are caused by different instructional designs, one might also argue that these effects may be caused by differences in attentional processes in learners (e.g., switching attention between different parts of the instruction; Brünken & Leutner, 2001). Although these different views do not contradict each other, it should be investigated in more detail how the different instructional design principles affect attentional processes.

The availability of the dual-task method for the assessment of cognitive load in multimedia learning has several theoretical as well as practical implications. On the theoretical side, the method for the assessment of cognitive load described in this article allows us to validate other research findings on cognitive load, such as the expertise reversal effect or contiguity effect, based on a direct measure of load. To study these effects, new secondary tasks need to be developed. This will also allow for deeper insights into the nature of individual differences, such as verbal and spatial ability, and their effect on cognitive load.

On the practical side, the dual-task method for the measurement of cognitive load can be used for the evaluation of multimedia instruction and the amount of load it induces for particular learners. It can also help answer the questions as to whether cognitive load can indeed be reduced through training.

Although no single measure is ideal, we believe that adding a dual-task approach to the existing measures of cognitive load will allow for a more valid and reliable assessment of cognitive load in multimedia learning environments.

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