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List of Abbreviations

AOI	Area of Interest
ATP	Adenosine Triphosphate
CATLM	Cognitive Affective Theory of Learning with Media
CLT	Cognitive Load Theory
CTML	Cognitive Theory of Multimedia Learning
ECG	Electro Cardiogram
EDA	Electro Dermal Activity
EEG	Electro-Encephalography
fMRI	Functional Magnetic Resonance Imaging
ICA	Index of Cognitive Activity
ISM	Inventory of School Motivation
MANCOVA	Multivariate Analysis of Covariance
MANOVA	Multivariate Analysis of Variance
NASA TLX	NASA Task Load Index
t1	measuring time one
t2	measuring time two

Overview of relevant publications

The present dissertation is a cumulative dissertation that is focused on cognitive load while learning with multimedia instructions and the comparison and validation of methods for cognitive load measurement. The dissertation comprises three empirical studies (publications I, III, & IV) that were published in international scientific peer-reviewed journals and one publication that is submitted to an international scientific journal for peer review (publication II).

Publication I

Park, B., Korbach, A., & Brünken, R. (2015). Do learner characteristics moderate the seductive-details-effect? A cognitive-load-study using eye-tracking. *Journal of Educational Technology & Society, 18*, 24-36.

Publication II

Korbach, A., Brünken, R., & Park, B. (accepted). Measurement of Cognitive Load in Multimedia Learning: A Comparison of Different Objective Measures. *Instructional Science*.

Publication III

Korbach, A., Brünken, R., & Park, B. (2016). Learner Characteristics and Information Processing in Multimedia Learning: A Moderated Mediation of the Seductive Details Effect. *Learning and Individual Differences*, *51*, 59-68.

Publication IV

Korbach, A., Brünken, R., & Park, B. (accepted). Differentiating Different Types of Cognitive Load: A Comparison of Different Measures. *Educational Psychology Review*.

Personal contribution of the PhD candidate

Publication I: Data analysis and writing of the scientific publication

Publication II: Data acquisition, analysis and writing of the scientific publication

Publication III-IV: Formulation of research questions, data acquisition, analysis and writing of the scientific publications

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Cognitive load measurement while learning with multimedia

1. Introduction

Cognitive load theory (CLT; Choi, van Merriënboer, & Paas, 2014; Plass, Moreno, & Brünken, 2010; Sweller, Ayres, & Kalyuga, 2011) is one of the most influential theories for research on learning and instruction, especially for learning with multimedia learning instructions. The former model of CLT (Sweller, van Merriënboer, & Paas, 1998) thereby assumes the existence of intrinsic cognitive load that is based on task complexity, extraneous cognitive load that is based on the presentation format and germane cognitive load that is based on cognitive processes relevant to learning. The recent model of CLT (Choi et al., 2014; Kalyuga, 2011) only considers intrinsic and extraneous cognitive load, including the learning-relevant cognitive processing in the intrinsic cognitive load factor. Cognitive load and the efficient use of available cognitive capacities are essential for learning and one big goal of cognitive load research is to derive practical implications for the design of learning instructions that support the efficient use of the learner's cognitive capacities. To this end, the use of valid and reliable methods of cognitive load measurement is very important (Brünken, Seufert, & Paas, 2010) and the present lack of appropriate standardized methods is highly relevant for cognitive load research. The present dissertation pays attention to the problem of cognitive load measurement, not only because of the importance for research on learning and instruction but also because of the need for evidence concerning the basic theoretical assumptions of CLT. The first study (publication I) therefore reviews eye-tracking as a method to assess cognitive load while learning with multimedia. The second (publication II) as well as the fourth study (publication IV) focus on a comparison between different methods of cognitive load measurement. For the development of learning instructions that save cognitive resources by optimizing information presentation and at the same time foster generative cognitive processing in accordance with the cognitive theory of multimedia learning (Mayer, 2001; 2005), methods are required to identify cognitive load in relation to the corresponding cognitive processes. Furthermore, to determine the unique contribution of certain cognitive processes to different cognitive load aspects, it is important to answer significant theoretical questions concerning the model construction of CLT with either three (Sweller et al., 1998) or two (Choi et al., 2014; Kalyuga, 2011) different kinds of cognitive load and the interrelationship of the single cognitive load factors. Therefore, different objective methods of cognitive load measurement will be validated concerning their suitability to measure total cognitive load. Moreover, the methods will be reviewed concerning their suitability to differentiate between different cognitive load factors. This was already shown for subjective cognitive load ratings in recent studies by Leppink and colleagues (Leppink & Van den Heuvel, 2015; Leppink, Paas, Van der Vleuten, Van Gog, & Van Merrienboer, 2013; Leppink, Paas, Van Gog, Van der Vleuten, & Van Merrienboer, et al., 2014). The studies show that the different cognitive load factors can be distinguished and measured separately. Thereby the studies switch from a subjective rating scale for the former three-factorial model to an adjusted rating scale for the recent two-factorial model of CLT and finally support the assumption of the two factors, intrinsic and extraneous cognitive load. These studies support the assumption of unique cognitive processes related to the single cognitive load factors and raise the question whether these cognitive processes can also be identified with objective methods. Given the assumptions of Schnotz and Kürschner (2007) concerning cognitive load and the zone of proximal development, instructional designs should rather aim at a moderate level of cognitive load that lies within the learner's zone of proximal development. That means efficient generative processing as a function of task difficulty and expertise for the zone of proximal development neither needs very high nor very low cognitive load. As there are no standardized measures for cognitive load and the zone of proximal development is a highly individual function, it is hard to determine an individual moderate level of cognitive load. Even methods for differentiating cognitive load measurement of the single cognitive load factors may not solve the problem. However, if at least extraneous and intrinsic cognitive load could be measured separately, this would help to distinguish the unique contributions of the single cognitive load factors to the total amount of cognitive load and to make assumptions concerning a cognitive overload or a cognitively unchallenging learning situation. The total amount of cognitive load is of course not only caused by the learning instruction but also by learner characteristics. The cognitive affective theory of learning with media (Moreno, 2009) as well as the updated model of cognitive load theory (Choi et al., 2014; Kalyuga, 2011) pay attention to learner characteristics and consider moderating effects for cognitive processing, corresponding cognitive load and resulting learning success. Thereby, cognitive load is assumed to result as a function of task-learner-interaction that not only affects the efficiency of resource consumption but also the individual capacity limitations. The task-learner-interaction is based on the assumption that cognitive processing depends on individual learner characteristics that offer possibilities to compensate for inappropriate instructional designs or high task complexity and that may offer strategies for efficient learning. Thus, not only the total amount of cognitive load but also the nature of cognitive load depend on learner characteristics. A recently discussed factor for determining cognitive load concerning the task-learner-interaction is element interactivity (Chen, Kalyuga, & Sweller, 2016; Kalyuga & Singh, 2015; Sweller, 2010). Based on Sweller's (2010) assumptions that element interactivity depends on intrinsic, extraneous and germane cognitive load, element interactivity is discussed as the main source of working memory capacity consumption. The number of active elements that must be activated and maintained in working memory can for example be increased by a high task complexity, a spatially or temporally separated information presentation as well as by a high engagement in schema acquisition. Moreover, the element interactivity effect indicates that, in general, cognitive load effects depend on element interactivity (Sweller et al., 2011) and do not occur in low element interactivity learning situations. As the learners' prior knowledge is a crucial factor for individual levels of element interactivity, Chen et al. (2016) even suggest to assume the expertise reversal effect as a variation of the element interactivity effect and to analyze element interactivity between different instructional designs to review the efficiency of the instructional procedures. Another learner characteristic that is at first sight not related to element interactivity — but still is important for learning success while learning with multimedia learning instructions — is the learner's spatial ability. High spatial ability learners seem to profit more from concurrent presentations of text and corresponding picture information (Gyselinck, Ehrlich, Cornoldi, De Beni, & Dubois, 2000; Mayer & Sims, 1994) and have advantages concerning the construction of three-dimensional mental representations out of two-dimensional visual figural information (Mayer, 2001; Münzer, Seufert, & Brünken, 2009). Thereby, spatial ability is assumed to support efficient generative processing and to save cognitive resources for handling high task complexity or high extraneous cognitive load. The present work considers learner characteristics especially concerning the efficient use of cognitive capacity when dealing with high extraneous cognitive load to provide explanations for contradicting results of cognitive load research. The first study (publication I) and especially the third study (publication III) focus on the task-learner-interactions and use analysis of moderation and moderated mediation to show the influence of prior knowledge and spatial ability. Even though spatial ability is not directly related to element interactivity, the results of both studies will finally be discussed with regard to the element interactivity effect. In summary, the goals of the present dissertation are to compare and to validate different methods of cognitive load measurement and to make conclusions concerning the basic theoretical assumptions of CLT. Thereby, the interrelations between the single cognitive load factors and the impact of individual learner characteristics will be considered to review the basic theoretical assumptions of CLT. Furthermore, the results of the different cognitive load measures will be reviewed concerning their sensitivity to cognitive processes that indicate a unique contribution to the single cognitive load factors.

2. Recent Models of Cognitive Load Theory

Cognitive Load Theory (Choi et al., 2014; Plass et al., 2010; Sweller et al., 2011) is a commonly used theoretical framework in empirical research on learning and instruction. One basic assumption of cognitive load theory is that the available cognitive capacity is limited by working memory capacity and that knowledge acquisition is an active process that is fostered by an efficient use of available resources. The objective of CLT is to provide explanations for learning performance as a function of resource consumption and to support the design of efficient learning instructions. At first, CLT focused mainly on resource consumption by instructional methods (Sweller, 1989); over time, additional resource consumption due to task demands (Sweller, 1994) and cognitive activity for schema acquisition (Sweller et al., 1998) were added to the theory and merged within the additivity hypothesis (Paas, Renkl, & Sweller, 2003).

2.1 Three-Factorial Model

The three-factorial model of CLT (Plass et al., 2010; Sweller et al., 2011) assumes three components: (1) intrinsic, (2) extraneous, and (3) germane cognitive load (Sweller et al., 1998) that add up to the total amount of cognitive load (Brünken, Moreno, & Plass, 2010; Moreno & Park, 2010; Park, 2010). Intrinsic cognitive load is determined by the given complexity of the learning task and results from element interactivity. Element interactivity is defined by the number of interacting information elements that belong to the learning task and that have to be processed simultaneously in working memory. The more complex the learning task, the higher the element interactivity and the resulting intrinsic cognitive load. To some extent, intrinsic cognitive load can be reduced by instructional design that reduces element interactivity (Pollock, Chandler, & Sweller, 2002) but primarily, intrinsic cognitive load is a function of individual prior knowledge and expertise (Kalyuga, Chandler, & Sweller, 1998; Paas et al., 2003). Schemata that already have been learned and automated by the learner thereby reduce the number of interacting elements because multiple elements that were already integrated into a schema can further be handled as a single element. Extraneous cognitive load is caused by the instructional design, hinders the learning process and should therefore be reduced to a minimum. As the extraneous cognitive load factor was the origin of CLT, most cognitive load effects and design principles focus on the objective to reduce extraneous cognitive load and to free cognitive capacity for schema acquisition (Moreno & Park, 2010). An increase in extraneous cognitive load means an increase in cognitive capacity due to the compensation of poor instructional design that does not foster schema construction. Extraneous cognitive load is increased, for example, if corresponding information is presented at high spatial distance to another (Spatial Contiguity Effect, e.g. Moreno & Mayer, 1999) or is temporally delayed instead of simultaneously presented (Temporal Contiguity Effect, e.g. Mayer & Sims, 1994). Both effects cause cognitive load to keep the corresponding information up in working memory over an unnecessary long period of time instead of saving resources for mentally integrating the corresponding information. In contrast, germane cognitive load is the amount of load that is directly dedicated to schema acquisition and automation. An increase in germane cognitive load within the limitations of working memory capacity thereby means an increase in learning performance. Free cognitive capacity should be used to handle the intrinsic cognitive load and to organize and integrate the interacting elements into coherent schemata (Sweller, 2010). Given a learning content of high intrinsic cognitive load, the goal of a proper instructional design should be a low extraneous cognitive load and a redirection of the free capacity towards germane cognitive load. According to this conclusion, instructional techniques to foster germane cognitive load should be aimed at the redirection of free cognitive resources to the cognitive processes of schema construction.

Criticism on CLT mainly addresses the three-factorial structure and the additivity hypothesis. Concerning the additivity of the single cognitive load factors especially intrinsic cognitive load seems not to be simply additive. On the one hand, intrinsic cognitive load has to be distinguished from extraneous and germane load by its nature because — in contrast to these loads — intrinsic cognitive load is assumed to be solely inherent to the material. On the other hand, a close relation and even an interaction between intrinsic and germane cognitive load must be assumed because germane load is devoted to handle intrinsic load (De Jong, 2010). Both assumptions question a simple additivity of the three cognitive load factors. Research on the additivity hypothesis supports this concern as there is no evidence for a simple additive relation of intrinsic, extraneous and germane cognitive load (Park, 2010; Park, Moreno, Seufert, & Brünken, 2011). Furthermore the distinctiveness and the unique contribution to total cognitive load of the single cognitive load factors is problematic and widely discussed. Schnotz and Kürschner (2007) state that it is a function of the educational objective as well as of the learners' expertise whether a load is intrinsic or extraneous. Thereby, a high intrinsic load for experts may foster learning performance in contrast to novices who cannot handle the large number of interacting elements and the intrinsic load in turn becomes extraneous load that hampers learning performance. Germane load should further not be considered to be a requirement for learning because implicit learning can also occur without involvement of working memory as defined for schema acquisition within CLT and so without germane cognitive load. This is not only true for evolutionary primary knowledge but also for culturally mediated secondary knowledge (Geary, 2007, 2008) that is the concern of CLT. Based on these assumptions, Schnotz and Kürschner (2007) suggest that germane cognitive load should be defined as additional load due to additional cognitive processes that improve learning. De Jong (2010) states a close relation between extraneous and germane cognitive load, as a reduction of extraneous load by a well integrated design may also lead to an increase in germane load. Furthermore, the distinction between germane and extraneous cognitive load may depend on learner characteristics, as that holds true for the expertise reversal effect. The same instructional techniques that foster schema construction for novices hamper schema construction for experts and turn out to be germane load or extraneous load as a function of the learners' prior knowledge (Kalyuga, Ayres, Chandler, & Sweller, 2003). Sweller (2010) states element interactivity as the main source for working memory capacity consumption and as a common factor for intrinsic, extraneous and germane cognitive load. Thereby, the suggestion to distinct intrinsic and extraneous cognitive load is two-fold. First, the difference between extraneous and intrinsic depends on the effect of changing element interactivity. If changes in element interactivity alter the learning objective, the concerned resource is intrinsic; if not it is extraneous. Second, the difference between extraneous and intrinsic depends on the learning objective itself as an element can be intrinsic if it is part of the learning objective and the same element can be extraneous if it is no part of the learning objective. Germane cognitive load is defined as a function of intrinsic and extraneous cognitive load. Thereby, the resources that were not consumed by extraneous load can be distributed to handle the intrinsic load that results from element interactivity. This close interaction of intrinsic and germane cognitive load leads Kalyuga (2011) to the conclusion that these two factors can essentially not be distinguished. Intrinsic cognitive load is defined by element interactivity and the real load results from processing these elements that were part of the learning objective. The processing of these elements leads to schema acquisition that is at the same time considered to cause the germane cognitive load. Thus, intrinsic and germane cognitive load at least share the cognitive processes that were due to schema acquisition and therefore the three-factorial structure is to some extent redundant.

2.2 Two Factorial Model

Based on the criticism about missing unique characteristics needed to distinguish between intrinsic and germane cognitive load, an updated model of CLT considers only two of the three components: intrinsic and extraneous cognitive load (Choi et al., 2014; Kalyuga, 2011). The deletion of germane load was due to the close relationship between intrinsic and germane cognitive load, which manifested in the inability to separate a unique contribution of each factor to the overall cognitive load. Germane cognitive load is now considered as germane resources that reflect the actually allocated amount of working memory capacity for learning and the learners' engagement in the learning activity (Sweller, 2010). Germane cognitive resources can be increased by instructional techniques that increase the learners' engagement in the learning activity. The cognitive load that is caused by schema acquisition is incorporated into the intrinsic cognitive load factor as intrinsic cognitive load represents the essential processing of the learning task. Instructional techniques to foster schema acquisition and to increase former germane cognitive load are assumed to raise the number of interacting elements and to belong to intrinsic cognitive load within the updated model. Element interactivity remains the crucial factor for intrinsic cognitive load and the cognitive demands of the learning task. However, the task characteristics are further redefined according to the intrinsic task difficulty, the type of task and the manner of instructional design and distinguished from the physical learning environment. The physical learning environment is considered as a surrounding situational factor that interacts with the learner and the task characteristics and has cognitive, physiological and affective effects on learning (Choi et al., 2014). The effects of the physical learning environment can cause additional extraneous cognitive load, for example via seductive noise that has to be ignored and affects the focus of attention, but they can also foster germane cognitive resources, for example by providing a motivating learning environment. In sum, the updated model not only reduced the number of capacity consuming load factors but also adapted to cognitive-affective, motivational and evolutionary perspectives and theories.

One more criticism that led to the updated two-factorial model of CLT is the problem of differentiating measurements of the single cognitive load factors. Due to a lack of differentiating methods of cognitive load measurement, many studies only quantify total cognitive load and interpret the results according to the learning performance as intrinsic, extraneous or germane cognitive load (De Jong, 2010). The post-hoc explanation thereby allocates high cognitive load in combination with high learning success to germane cognitive load and in turn high cognitive load in combination with low learning success to extraneous cognitive load. However, high cognitive load in combination with high learning success can also be due to high intrinsic cognitive load (Schnotz & Kürschner, 2007). In fact, the feasibility to methodologically distinguish between germane and intrinsic cognitive load is highly problematic and there is a lack of studies that prove a unique contribution of germane load that cannot be explained by intrinsic load (Kalyuga, 2011). Considering synergetic effects of instructional techniques that influence more than one load factor, for example by decreasing extraneous and increasing germane load at the same time, demonstrates the insufficient reliability of the approach to quantify only total cognitive load. Although the updated model includes only intrinsic and extraneous cognitive load, there is still a need for methods of cognitive load measurement to distinguish at least between these two factors of CLT. Synergetic effects of instructional techniques can also be assumed for the updated model of CLT with a decrease in extraneous and a simultaneous increase in intrinsic cognitive load due to intense information processing. The reunion of intrinsic and germane cognitive load may provide an advantage for methods of cognitive load measurement but the methodological problem to distinguish between the two factors remains. There may be no need to further distinguish intrinsic load solely according to task performance and germane load according to essential learning performance. However, there is a need for valid and reliable methods to distinguish between intrinsic and extraneous cognitive load to disentangle effects of instructional techniques on cognitive load considering the moderating interaction of task demands and learner characteristics.

2.3 Cognitive Load Theory and the Cognitive Theory Of Multimedia Learning

The Cognitive Theory of Multimedia Learning (CTML; Mayer, 2001, 2005) is based on three theoretical assumptions. First, the dual channel assumption that assumes separate channels for visual/pictorial and auditory/verbal information processing. This assumption is related to the dual coding theory (Paivio, 1986) as well as to theories of working memory (Baddeley, 1986, 1998) and considers the sensory modality that is visual or auditory as well as the presentation mode that is pictorial or verbal. Thereby, the sensory modality is essential to the perceptual processing and the presentation mode is essential to the construction of verbal or pictorial mental models in working memory. Furthermore, the assumption of cross-channel representations (Paivio, 1986) includes the possibility to transfer information presented to one channel to be also represented in the other channel. Second, the limited capacity assumption is based on theories about working memory (Baddeley, 1998, 2002; Chandler & Sweller, 1991) and considers a limited cognitive capacity that can be used for information processing. This assumption is congruent with CLT (Sweller, 1999), however with regard to the dual channel assumption CTML assumes separate capacities for the single processing channels. Third, the active processing assumption that is also identically featured in CLT (Sweller, 1999) and assumes that learning is an active cognitive process in order to construct a coherent mental model (Wittrock, 1990). The essential cognitive processes for active learning are, according to CTML, the selection of the relevant information, the organization of the relevant material and the integration of the selected material with existing knowledge. The relevant cognitive system for active processing is the working memory and information that shall be organized or integrated must first be transferred from sensory memory and activated from long-term memory. Mayer (2005) assumes five essential processes for meaningful learning, which are (1) selecting relevant words, (2) selecting relevant pictures, (3) organizing selected words, (4) organizing selected pictures and (5) integrating the verbal and pictorial representations with each other and with prior knowledge. Selecting thereby means to pay attention to the most important parts of the presented information so that they can be transferred to working memory via the corresponding processing channel. The information selection is necessary because of the limited capacity of working memory that only allows processing a limited number of information elements at once. Organizing means the construction of a coherent representation out of the selected information and is also subject to the capacity limitations for the different processing channels. According to the sensory modality and the presentation mode the organization leads to a verbal or a pictorial model whereas verbal information that was presented visually can be transferred to a verbal model that is processed in the auditory channel. The final integration of the verbal and the pictorial models means to build relations and to map the corresponding information of each representation to each other and to prior knowledge. The process of integration can be assumed to be highly demanding and therefore an efficient use of the available cognitive capacity is necessary for meaningful learning. Successfully integrated new information will be transferred and stored in long-term memory in form of schemata that can be used as prior knowledge for the further learning process. This model of CTML (Mayer, 2001, 2005) was expanded to the Cognitive Affective Theory of Learning with Media (CATLM; Moreno, 2005, 2006, 2007, 2009) by adding motivational and affective aspects to close the gap between affective and cognitive processes. CATLM includes three more assumptions which are the affective mediation assumption, the metacognitive mediation assumption and the individual differences assumption. These assumptions consider affective and motivational processes, metacognitive functions and individual learner characteristics to mediate the cognitive processing while learning with media.

In sum, at least the limited capacity assumption and the active processing assumption are identical between CLT and CTML/CATLM. CLT (Sweller, 1999) thereby differs between intrinsic, extraneous and germane cognitive load, whereas CTML/CATLM differs between extraneous, essential and generative processing. However, the three different types of load and processing can easily be related to each other, CLT and CTML/CATLM do not specify the detailed cognitive processes that are unique to extraneous, intrinsic and germane cognitive load or extraneous, essential and generative processing. For CTML/CATLM Mayer and Moreno (2007) assign the selecting of information to essential processing and organizing and integrating information to generative processing. The problems concerning the suggested categorization thereby are similar to CLT and the differentiation between intrinsic and germane cognitive load. For one, selecting information might also be related to extraneous processing; secondly, there might be interactions between essential and generative processing comparable to interactions between intrinsic and germane cognitive load for CLT.

Concerning the mediation assumptions of CATLM (Moreno, 2006; Moreno & Mayer, 2007) especially the former model of CLT (Plass et al., 2010; Sweller et al., 2011) does not pay much attention to motivational, affective and metacognitive aspects or individual learner characteristics. In contrast, the updated model of CLT (Choi et al., 2014; Kalyuga, 2011) comes close to these mediation assumptions and considers such additional factors within the revised germane cognitive resource concept. To map the different theories to each other, extraneous cognitive load can be related to extraneous cognitive processing, intrinsic cognitive load to essential cognitive processing and germane cognitive load to generative cognitive processing for the three-factorial model of CLT (Plass et al., 2010; Sweller et al., 2011). With regard to the two-factorial model of CLT (Choi et al., 2014; Kalyuga, 2011), essential and generative cognitive processing can be both assigned to intrinsic cognitive load and the concept of germane cognitive resources pays attention to the mediation assumptions of CATLM (Moreno, 2006; Moreno & Mayer, 2007). In sum CLT, CTML and CATLM share several commonalities including the problem of identifying unique cognitive processes at witch this problem is essential to CLT because CTML and CATLM do not want to explain learning in terms of cognitive load (Moreno, 2010). However the information selection, organization and integration can be assumed as the essential cognitive processes for learning. Moreover the proper classification of the causal cognitive processes is very important for a valid and reliable measurement of cognitive load and a differentiation of the single cognitive load factors.

3. Cognitive Load Measurement

In general, there is a lack of standardized, reliable and valid measures for CLT research especially for the differentiated assessment of the three respectively two main constructs (Kirschner, Ayres, & Chandler 2011; Moreno, 2010). Many studies do not assess cognitive load directly but interpret cognitive load effects indirectly according to measures of learning success. The use of self ratings for cognitive load is widespread in the field of cognitive load research; however, rating scales are criticized because of methodological problems (Brünken, Plass, & Leutner, 2003; Brünken et al., 2010; Clark & Clark, 2010; Moreno, 2006). Furthermore physiological measures can be used to assess cognitive load and emerging technologies like eye-tracking provide a detailed insight into human information processing. Brünken et al. (2010) provide a classification of cognitive load measures according to the source of information about the resource consumption that distinguishes subjective, objective or combined methods. This classification is used in the following to describe the currently used methods of cognitive load measurement.

3.1 Subjective Measures

Subjective methods commonly used are ratings of perceived mental effort, task difficulty or engagement, which are completed by research participants. Two examples for widely used subjective rating scales are the scale introduced by Paas (1992) and the NASA Task Load Index (NASA TLX; Hart & Staveland, 1988). The self-report scale of Paas (1992) is probably the most frequently used scale for a fast and easy assessment to perceived cognitive load. The scale is a one item scale that asks for the perceived mental effort on a 7- to 9-point Likert scale. The item is often combined with a rating of perceived task difficulty (Paas, Tuovinen, Tabbers, & Van Gerven, 2003). The advantage of subjective methods is that ratings provide valid and reliable information about the individual learning experience. In addition, subjective rating scales are very easy to implement and can be used in different learning contexts with diverse learning contents and groups of participants. Several studies show the suitability of rating scales for cognitive-load measurement (Gopher & Braune, 1984; Paas & van Merriënboer, 1994). Specifically, the ratings for task difficulty seem to provide valid information about the intrinsic cognitive load based on element interactivity as defined for the three-factorial model of CLT (Ayres, 2006).

However, rating scales are criticized because of methodological problems concerning the quality criteria of objectivity, validity and reliability (Brünken et al., 2003; Brünken et al., 2010; Clark & Clark, 2010; Moreno, 2006). In particular, evidence for content validity is critical, as it is difficult to distinguish between different types of cognitive load with a universal subjective rating scale. The ratings of perceived task difficulty for example can also be influenced by changes in germane and extraneous cognitive load because changes in all three factors of CLT may cause a perceived higher task difficulty. Considering task-learner interactions and synergetic effects between different cognitive load factors, these subjective ratings may rather provide information about total cognitive load for the commonly used learning environments. Nevertheless, subjective rating scales are assumed to be the only way to distinguish the single cognitive load aspects, using multi-dimensional questionnaires to separately assess intrinsic, extraneous and germane or rather intrinsic and extraneous cognitive load, respectively (Leppink & Van den Heuvel, 2015; Leppink et al., 2013; Leppink et al., 2014).

Another disadvantage is that ratings are generally requested after the learners have finished the learning task. Rating scales provide no continuous information about the actual cognitive load during the learning process. Given a complex learning task with fluctuating task demands depending on task-learner-interactions subsequent ratings provide only a global scaling across the perceived cognitive load of the whole learning task (Brünken et al., 2010). In contrast, frequent intermediate ratings may interrupt the learning process for several times and thereby hamper the schema construction especially when multidimensional questionnaires should be used within a complex learning task. Furthermore, there is an effect of timing for cognitive load ratings (Schmeck, Opfermann, Van Gog, Paas, & Leutner, 2015; Van Gog, Kirschner, Kester, & Paas, 2012) with delayed ratings of mental effort and task difficulty indicating higher cognitive load than immediate ratings. These findings underline the strong subjective aspects of cognitive load ratings concerning perception, introspection and retrospection. However, given these drawbacks, subjective ratings of cognitive load are still often used in research examining learning and instruction because of the important benefits concerning usability. Nevertheless, there is a need to complement subjective methods with additional objective methods especially concerning a continuous measurement of cognitive load during the learning process.

3.2 Objective Measures

Objective methods of cognitive-load measurement include measures of learning outcomes, task difficulty and behavioral data (Brünken et al., 2010). The interpretation of learning outcomes is based on the experimental manipulations of the cognitive load factors by different instructional designs and effects on learning outcomes are assigned according to the theoretical assumptions for the independent variable. As for the practical implications of examined instructional techniques, the measurement of learning outcomes is important for cognitive load research. However, it is not a valid measure for cognitive load because concurrent factors cannot be excluded from affecting the learning outcomes and cognitive load can neither be quantified nor can effects on the single factors be distinguished. The approach to use task complexity as a measure for cognitive load is very close to the measurement of learning outcomes. The basic assumption is that task difficulty varies the cognitive load consumption with easy tasks consuming less cognitive resources than difficult tasks (Ayres, 2006). However this approach does also not provide detailed information about cognitive load, because the learning outcome as well as the task difficulty depend on prior knowledge (Kalyuga, 2003) and both methods cannot be used to continuously measure cognitive load. In contrast, many methods to measure behavioral data provide much more detailed information about cognitive load and allow a continuous measurement. Behavioral data include the analysis of time on task, physiological data such as pupil dilation, heart rate or data from methods of neuroimaging, secondary-task performance and eye-tracking data. Except for time on task, each of these mentioned objective methods is essential due to the continuous nature of the measurement and provides highly detailed information about cognitive load during the learning process.

Time on task is easy to measure and directly related to the invested effort and engagement for the learning task. The basic assumption is that cognitive processes need time to be performed and that the time on task increases according to the amount of cognitive processes that are performed within a learning task. However, time on task does also not measure cognitive load directly. In contrast, some physiological measures can directly indicate cognitive load. Whelan (2007) argues that functional magnetic resonance imaging (fMRI) not only can measure cognitive load directly but also can differentiate between the single load factors by showing specific neuronal activation patterns for intrinsic, extraneous and germane cognitive load. As a further development of the electro-encephalography (EEG) that also can be used to measure cognitive load, the fMRI provides much more detailed information due to a higher resolution. The disadvantage of these techniques is the complexity of the instrument and the low flexibility for a use in combination with common multimedia learning environments. The electro cardiogram (ECG) can also be used to detect individual changes to cognitive load by a learning task. However, the differences seem to be very small and hard to show (Paas & Van Merrienboer, 1994). Another method to detect cognitive load is the electro dermal activity (EDA) that is based on perspiration resorption (Schwalm, 2009). A study by Verwey and Veltman (1996) showed an increase in cognitive load during a driving simulation by adding an additional cognitive task. In general, the problem with neuroimaging techniques is usability — especially considering a large sample size or a natural learning environment.

The measurement of secondary-task performance as a direct measure of cognitive load is based on the CLT's limited capacity assumption. Given a primary task that is a learning task with a certain amount of capacity consumption due to the instructional technique, the measurement of secondary-task performance provides information about the amount of cognitive capacity that is not used to perform the primary task. The prerequisite is that the secondary-task relies on the same cognitive resource as the primary task (Brünken et al., 2003). The dual-task approach has a long tradition in psychological research on working memory capacity and research on related cognitive components and processes according to task demands (e.g. Baddeley, 1986). Thereby, "dual-task" means that the participants have to perform two concurrent tasks and performance of both tasks is measured to identify common cognitive processes and resources. In research on learning and instruction the first task is of course the learning task. The established secondary-tasks are mostly fulfilled by auditory or visual cues in the learning instruction and use reaction time on these up-coming cues within the learning material as a measure for secondary-task performance and cognitive load. The dual-task method thereby allows direct measurement of cognitive load. A series of studies provides evidence that secondary-task performance produces reliable and valid results for cognitive load measurement (e.g. Brünken et al., 2003; DeLeeuw & Mayer, 2008). A special kind of secondary-task is the rhythm method that is a dual-task analysis with a rhythmic foot-tapping task as secondary-task (Park & Brünken, 2015). It measures cognitive load in a direct and continuous way using an intra-individual behavioral measure. The rhythm method uses no external cues and therefore avoids sensory interferences between the learning instruction and the secondary-task (Park & Brünken, 2015). This new method was validated in a study where the participants' primary task was to work with a multimedia-learning program and the secondary-task was to tap a previously presented and practiced rhythm with their foot. Because both tasks rely on the same cognitive resources, the performance of the secondary-task provides information about the amount of available cognitive capacities. For example, better performances on the secondary-task indicate that less cognitive capacities are consumed by the primary task. The given limitations are that secondary-task performance does also not provide an absolute estimation of resource consumption (Brünken et al., 2010), cannot distinguish between single cognitive load factors and often requires laboratory settings. Given the additivity hypothesis of cognitive load theory and the theoretical explanation that rhythm production is specifically dealing with inhibition processes associated with executive control (Park & Brünken, 2015), the sensitivity of this method should be associated with a general sensitivity for total cognitive load. Furthermore, the dual-task induces cognitive load by itself and there may be an impairment of the learning process dependent on possible interferences between the demands of the learning and the secondary-task. However, the dual-task approach provides continuous, valid and reliable information about cognitive load consumption for learning tasks.

Another possibility to measure cognitive load in a less intrusive way lies within the pupillometric analyses. The techniques to record eye movements achieved large improvements concerning usability over the last years. The pupil size and the pupil dilation also provide information about cognitive activity and cognitive load (Beatty, 1982). Laeng, Ørbo, Holmlund, & Miozzo (2011) replicated the Stroop effect with an increase in pupil size and larger pupil dilations for color incongruent distractors. Hyönä, Tommola and Alaja (1995) found the pupil size to be an indicator for cognitive load during word translation. However, the tasks of both studies are very simple compared to a multimedia learning instruction. Two more studies found pupil size to be an indicator for cognitive load during tasks that are closer to a complex learning task with mixed media presentation. Just and Carpenter (1993) found evidence for the sensitivity of the pupil size concerning the cognitive load during sentence reading and text comprehension, with larger mean pupil dilation for complex sentences. Moreover, Van Orden, Limbert and Makeig (2001) found a relation between pupil size and task difficulty in a target identification task, with an increase in pupil size for tasks with a higher level of difficulty. In this experiment, the task demands called for the processing of pictorial and textual information, presented together on a single slide. In addition, both studies analyzed larger time intervals and extend the often used event related pupil response within very close time intervals of about one or two seconds. The disadvantage of pupillometric analysis is that pupil size can be influenced by illumination effects and is also sensitive to other factors like emotion or arousal (Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka, & Van De Weijer, 2011). This problem is not only true for pupillometric analysis but for

EEG, ECG and EDA because the measured arousal cannot clearly be ascribed to cognitive load and so there is also the question of construct validity.

A method that was developed to exclude effects of illumination and emotional arousal for pupillometric analysis is the index of cognitive activity (ICA) introduced by Marshall (2007). The ICA is based on the short and large reactions in pupil dilation due to changes in cognitive activity that are identified by wavelet analysis and automatically calculated by designated analytics software (EyeWorksTM, EyeTracking Inc.). The advantage of the ICA is that the large dilations in pupil size due to effects of illumination are automatically identified and excluded from analysis. Marshall, Pleydell-Pearce, and Dickson (2002) demonstrated that the ICA is not influenced by illumination and that the ICA reliably indicates cognitive load under high and low illumination conditions. Some recent studies support the usability of the ICA for driving tasks (Demberg, Sayeed, Mahr, & Müller, 2013; Schwalm, Keinath, & Zimmer, 2008) or mathematical tasks (Schwalm, 2009), but not for learning within a multimedia instruction. Debue and van de Leemput (2014) used the ICA for cognitive load measurement concerning information processing with different types of online newspapers. However, the ICA values did not conform to the results of subjective cognitive-load ratings or performance measures. As there are only few studies that used the ICA to measure cognitive load in a context that is comparable to complex learning with multimedia learning instructions, it is not certain if the ICA is a valid and reliable method for research on learning and instruction. However, there is evidence for its quality and advantages in the context of simple cognitive tasks that do not concern learning and the ICA should be adapted to instructional research and validated for cognitive load measurement within the context of complex learning.

Closely related to the pupillometric analysis is the analysis of gaze behavior and eye movements. The eye-tracking analysis offers many different measures that provide detailed information about information processing, the allocation of attention and cognitive activity. When used alone, eye-tracking provides information about the perceptual processing while learning; but in combination with measures of learning performance, it also provides information about the focus of cognitive activity and cognitive information processing (Folker, Ritter, & Sichelschmidt, 2005; Mayer, 2010). Measures like the total fixation time and the total number of fixations on relevant information, the time to the first fixation on relevant information or the transitions between related sections of relevant information can show the learners' focus of attention during perceptual processing. The established eye-tracking indicators for cognitive load or cognitive activity are fixations (Haider & Frensch, 1999; Jarodzka, Scheiter, Gerjets, & van Gog, 2010). As it is indicated by several studies, there is evidence for a close relation between eye-movement measures and cognitive activity that supposes e.g. long fixation time as an indicator for high cognitive activity (Just & Carpenter, 1976; Rayner, 1998). Especially during learning with text and graphic, total fixation time on the relevant graphic is hypothesized to cause cognitive processing and to serve as a measure of cognitive performance (Mayer 2010; Rayner, Li, Williams, Cave, & Well, 2007; Reichle, Rayner, & Pollatsek, 2003). Another measure of perceptual processing is the total number of fixations on the relevant picture. Just as the total fixation time the total number of fixations can be hypothesized as a reference for cognitive processing indicated by the perceptual processing engaged in the learning process. For both measures it is assumed that long fixation times and a large number of fixations indicate high cognitive activity (Canham & Hegarty, 2010; De Koning, Tabbers, Rikers, & Paas, 2010). Another measure, which is supposed to be closely related to cognitive processing, are the transitions between related sections of relevant information. In detail, transitions between text and related graphic information are assumed to represent integrative cognitive processes and to be directly related to schema construction out of textual and graphical information. Therefore, a large number of transitions is assumed to be associated with high cognitive engagement in integrating verbal and pictorial information (Schmidt-Weigand, Kohnert, & Glowalla, 2010). Cook, Wiebe, and Carter (2008) used the analysis of transitions between macroscopic and molecular representations to show differences between high and low prior knowledge students in their allocation of visual attention. Thereby, the different transition patterns are related to differences in the learning process due to their different states of prior knowledge. Johnson and Mayer (2012) differentiate several kinds of transition-based measures to identify related cognitive processes concerning the spatial contiguity effect. The group that worked with the integrated version of the learning instruction showed more integrative and corresponding transitions than the group that worked with the non-integrated design. According to the results, the difference in transition patterns is assumed to represent a difference in meaningful learning. All aspects considered, the analysis of eye movements provides detailed information about the allocation of visual attention that can be used to show differences in information processing between different instructional designs. However, eye movements as long fixation times and a large number of transitions are no unique indicators for high cognitive load and it is very difficult to get the link between the observable eye movements and the cognitive processes related to the single cognitive load factors. As the same eye movements can be caused by different aspects of an instructional design and depend on learner characteristics as well as on task-learner-interactions, the experimental design is of crucial importance

(Brünken et al., 2010). One possibility to enrich the analysis of eye movements are retrospective interviews in which learners were asked to report their cognitive processes during the learning activity while they were watching the video of their recorded eye movements (Jarodzka et al., 2010). The research on characteristic eye-movement patterns for the CLT related cognitive processes is still in its infancy but the outlook is promising and in combination with other cognitive load measures they may increase the ability to disentangle the cognitive activity according to the single cognitive load factors. However, eye-tracking technology is still quite expensive and often limited to a laboratory setup that limits its application to experimental setups with a large sample size.

3.3 Combined Measures

Combined measures of cognitive load calculate efficiency measures for the learning process (Paas & Van Merrienboer, 1993; Paas et al., 2003). The approach can be used to model the efficiency of the learning performance as a function of mental effort and learning performance. First, the values of the mental effort ratings and the learning performance are transformed to a comparable scale. Second, the difference between the standardized scores is calculated and divided by the root of two. The resulting score is the efficiency measure for the learning instruction and can be used to compare different learning instruction. A high instructional efficiency means that the perceived cognitive load is lower than expected for the resulting learning outcomes and vice versa. A three-dimensional approach combines two measures of mental effort with the values of learning performance (Tuovinen & Paas, 2004). The advantage of efficiency measures is that this method is easy to use and provides useful information concerning one goal of cognitive load research that is to improve learning instructions according to CLTs theoretical assumptions. However, it provides no absolute values for cognitive load and no possibility to differentiate between the single cognitive load factors. Furthermore, the criticisms for subjective rating scales are also true for the combined method because the ratings are part of the calculation.

There are many methods of cognitive load measurement that all come with different advantages and disadvantages and the benefits of each method have to be considered according to the research question at hand and the appropriate experimental design. Modern techniques allow to collect physiological data such as heart rate and electro dermal activity wirelessly and with less effort; eye-tracking and pupillometric analysis have become less and less intrusive within the last years, so these measures should be taken into account according to the developments concerning their usability. The methods that claim to provide absolute values for cognitive load are the neuroimaging techniques EEG and fMRI as well as the ICA as a subtype of pupillometric analysis. Given the high complexity of EEG and fMRI, the ICA is probably a chance for cognitive load research on learning and instruction. However, the ICA is rarely used for cognitive load measurement in the multimedia learning context and needs validation. For all other measures, the experimental design is of crucial importance in order to make conclusions about cognitive load concerning the theoretical assumptions of CLT. A future goal of cognitive load research might be to develop standardized methods for differentiated cognitive load measurement, to identify the related cognitive processes and to show evidence for the main constructs of CLT.

4. Experimental Variations of Cognitive Load

To analyze the suitability of different cognitive load measures, it is necessary to vary cognitive load in an experimentally controlled way. To get further information about the possibility to methodologically distinguish between the single cognitive load factors, it is also necessary to experimentally manipulate the individual types of cognitive load. Concerning the three-factorial model of CLT, the essential load factors are germane and extraneous cognitive load because intrinsic cognitive load can be assumed to be relatively constant according to individual task difficulty. According to the two-factorial model of CLT, extraneous and intrinsic cognitive load should be varied. In order to manipulate cognitive load in the recent studies (publications I to IV), seductive details were used to induce additional extraneous cognitive load and mental animation tasks were used to foster learning by an increase in germane/intrinsic cognitive load.

4.1 Seductive Details

Seductive details consist of additional information which is highly interesting, but not necessary to achieve the learning goal (Mayer, 2005). Seductive details can consist of additional irrelevant pictures, graphics, written or spoken text, background sounds or music that is added to a learning content. The goal of this additional information is to enrich the basic learning content in order to foster situational interest (Park, Flowerday, & Brünken, 2015) and to evoke learning-conducive affective processing in multimedia learning (Park, Plass, & Brünken, 2014; Plass, Heidig, Hayward, Homer, & Um, 2014; Um, Plass, Hayward, & Homer, 2012). Such additional, non-redundant and interesting but irrelevant information is called “seductive details”. Seductive details are often used to make the learning material more interesting and attractive to learners of all ages and every type of school including higher education at universities (Park, Flowerday, & Brünken, 2015); however, they can be harmful to the learning performance and decrease the learning success. This negative effect on learning performance is called “seductive details effect”. Research on the seductive details effect is somehow contradicting. Several studies have shown a detrimental effect of seductive details (Garner, Gillingham, & White, 1989; Harp & Maslich, 2005; Harp & Mayer, 1998; Lehman, Schraw, McCrudden, & Hartley, 2007;), whereas others have shown non-significant results (Garner & Gillingham, 1991; Hidi & Baird, 1988; Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Mayer, Griffith, Jurkowitz, & Rothman, 2008; Schraw, 1998). One explanation for the contrasting results is based on differences between these studies concerning task difficulty. Some studies that found a seductive details effect were using scientific texts that were probably more difficult in contrast to non-scientific text that were used for some studies having found no detrimental effect of seductive details. As task difficulty is an important factor for cognitive load consumption, it may seem logical to assume that the learners’ cognitive capacity plays a crucial role for the impact of seductive details. Moreover, task difficulty is highly dependent on the learners’ prior knowledge (Kalyuga et al., 2003) and learners with high prior knowledge can be assumed to experience a lower task difficulty and lower cognitive load in contrast to participants with low prior knowledge. A study by Park et al. (2011) showed that controversial results in seductive details research can be explained by an effect on cognitive load as the detrimental effect on learning performance was at first present under cognitive high loading conditions. Even though there is some inconsistence in literature, research on seductive details provides four explanations for the negative effect of seductive details: (1) cognitive overload, (2) diversion, (3) disruption or (4) distraction. A meta-analysis by Rey (2012) which compares 39 experimental effects concerning the four explanations suggests that a simple cognitive overload assumption might be insufficient and that the seductive details effect cannot be fully explained by one single explanation. A study by Harp and Mayer (1998) supports the diversion hypothesis that assumes an activation of inappropriate prior knowledge by seductive details and that new information is organized around the activated inappropriate schemata. The diversion hypothesis was tested in some studies by manipulating the presentation order of seductive details in the way that seductive details were presented at the beginning, interspersed or at the end of the learning material (Harp & Mayer, 1998). The results show that seductive details only had a detrimental effect on learning when presented before or within the learning session and thus support the assumption of schema interference. However, the results do not necessarily exclude the alternative explanations of disruption and distraction. The activation of inappropriate prior knowledge is perhaps only one part of the explanation or may even enable a disruption or a distraction in the learning process. Some studies could show a disruption of and a distraction from the learning process (Lehman et al., 2007; Rey, 2014; Sanchez & Wiley, 2006) and support the disruption hypothesis with a coherence disruption of the relevant information processing by seductive details. The distraction hypothesis assumes a distraction from the relevant information processing and a study by Lehman et al. (2007) supports the disruption hypothesis with a reduced reading time of relevant sentences in scientific text and a decreased recall of main ideas. A study by Sanchez and Wiley (2006) gives further support for the distraction hypothesis, as the results show that the learners' attention control is a crucial factor for the detrimental effect of seductive details. A study by Rey (2014) also supports the distraction hypothesis. Results show that seductive details distract the learners' attention and cause a perfunctory processing of the relevant information that indicates a distraction of the relevant information processing and the learning process. Of course neither the disruption nor the distraction hypothesis need the activation of inappropriate prior knowledge and the diversion hypothesis is no requirement for these explanations. The results of these studies support the assumption of a combined explanation (Rey, 2012) and suggest a combination of cognitive load, disruption and distraction explanation for the seductive details effect with an increase in extraneous cognitive load due to additional information processing and a distraction as well as a disruption of relevant information processing. The increase in extraneous cognitive load thereby relies on the learner's individual cognitive capacity and so the learner characteristics are of great importance to explain the seductive details effect.

The central assumption from a cognitive load perspective is that differences in performance are caused by different amounts of resource consumption when learning with or without seductive details, with higher extraneous cognitive load induced by the additional processing of the irrelevant information. The seductive details are easy to understand, can be processed independently from the relevant information and therefore should not affect task difficulty according to an increase in total element interactivity. A relatively constant intrinsic load as well as a synergetic effect with an increase in extraneous and a concurrent decrease in germane cognitive load can be considered for the three-factorial model of CLT. The assumptions concerning germane and intrinsic cognitive load concern only the former model of CLT (Plass et al., 2010; Sweller et al., 2011). With regards to the updated model (Choi et al., 2014), which only considers intrinsic and extraneous cognitive load, extraneous cognitive load is assumed to increase and therefore intrinsic cognitive load is assumed to decrease for the seductive details version. Given the limited capacity assumption of CLT, the synergetic effect between extraneous and germane/intrinsic cognitive load should especially be true for cognitive high loading learning situations when all available cognitive resources are needed to process the information of the learning instruction. Thereby only extraneous cognitive load is experimentally manipulated by seductive details and the synergetic effect relies on the decrease in available cognitive resources for cognitive processes dedicated to meaningful learning. With regard to Sweller's (2010) assumptions about element interactivity, the synergetic effect should result from an increase in element interactivity that is not part of the learning objective (extraneous) and a decrease in available cognitive resources to handle the element interactivity that is part of the learning objective (intrinsic). Based on these assumptions there are many possibilities for cognitive load measurement results that all depend on the construct validity. Methods that were sensitive to extraneous cognitive load should indicate an increase, methods that were sensitive to germane/intrinsic may indicate a decrease and methods that were sensitive to total cognitive load may either display an increase or even no change, depending on the allocation of the available individual cognitive capacity. To disentangle such interactions, cognitive load research needs methods to distinguish between the single cognitive load factors and to identify and assign the corresponding cognitive processes.

4.2 Mental Animations

While there is a large amount of studies focusing on methods to reduce extraneous cognitive load, there is only a small amount of studies that focus on methods to increase germane cognitive load. To increase germane cognitive load thereby means to increase the generative processing that is dedicated to schema acquisition and automation. Moreno and Mayer (2010) name the multimedia principle, the personalization principle, the guided activity principle, the feedback and the reflection principle as methods to increase generative processing. All of these methods aim to increase the learners' active processing as well as the cognitive resources assigned to the learning task. Interactive learning instructions, the use of comprehension questions, guided problem solving and prompting self-explanations can achieve the learners' active engagement in the selection, organization and integration of new information. Effects of the learners' motivation can thereby be expected to affect the available cognitive capacity as well as the engagement in the learning activity. Bodemer, Plötzner, Feuerlein, and Spada (2014) showed the benefits of guiding the learners to interactively map familiar and unfamiliar representations to support the mental integration of different sources of information. Bodemer, Plötzner, Bruchmüller, and Häcker (2005) increased learning performance by guiding the learners to actively relate and integrate different static representations before exploring dynamic and interactive representations. Hegarty (1992) showed the effectiveness of inferring motion from static presentations concerning the mental model construction of moving pulley-systems. Hegarty, Kriz, and Cate (2003) found a positive effect on learning performance for prediction tasks concerning the behavior of an operating system. Münzer et al. (2009) showed the effectiveness of enriched static presentations for an active mental animation process. A study by Seufert and Brünken (2006) tested the effects of surface level help and deep structure level help on learning performance in a 2 by 2 factorial design in combination with cognitive load measurement. Both kinds of help guide the learners to map different sources of information and foster the construction of coherent mental representations. Results show that the combination of surface level help and deep structure level help was most effective in increasing the learning success. Cognitive load was measured via subjective ratings (Paas, 1992) and extraneous load was assumed to decrease due to the surface level help while germane cognitive load was assumed to increase due to the deep structure level help. However the results of the cognitive load ratings do not confirm these assumptions, instead showing a decrease in cognitive load for deep structure level help and an increase in cognitive load for surface level help when presented with no deep structure level help. Thus, the group that received both types of help gave the lowest overall ratings for cognitive load levels. Considering these results, the study shows the benefits of supporting coherence formation but also the problematic use of subjective rating scales and the necessity of differentiated cognitive load measurement to disentangle synergetic effects between the single factors on total cognitive load.

Another method to increase germane cognitive load that was designed according to these findings about the possibilities to support mental model construction are mental animation tasks (Park, Münzer, Seufert, & Brünken, 2016). As the studies of Hegarty (1992), Hegarty and Just (1993) and Hegarty et al. (2003) show that the ability to mentally animate operating systems is essential to a learning process, the mental animation tasks focus on fostering the mental animation process. To this effect, the mental animation tasks prompt mental rotation and manipulation of a given representation to foster the construction of a coherent mental representation. The tasks are designed to guide the learners' engagement in information selection, organization and integration and to increase generative cognitive processing. The theoretical assumptions underlying the beneficial effects of increasing germane cognitive load rely on CTML (Mayer, 2001, 2005, 2009) and CLT (Plass et al., 2010; Sweller, 1999; Sweller et al., 2011). For methods aiming at increasing germane cognitive load — such as these mental animation tasks — an increase in generative cognitive processing is assumed by fostering an intense information processing and a higher cognitive activity regarding the mental model construction. Intrinsic cognitive load is assumed to be constant for methods attempting to increase germane cognitive load because they do not add new elements to the learning content. However, the number of interacting elements may be increased due to the instructions to rotate, map and integrate different forms of representations. According to the additional task instructions and comprehension questions the number of active elements in working memory should be increased. Concerning the former model of CLT (Plass et al., 2010; Sweller et al., 2011), this assumption again highlights the difficulty to differentiate between intrinsic and germane cognitive load. With regard to the influence of individual learner characteristics, the increased cognitive load might rather be intrinsic than germane, depending on the individual available cognitive capacity. In general though, the increase in cognitive load is assumed to be germane cognitive load for the three-factorial model of CLT. The advantage of the updated model of CLT (Choi et al., 2014), which only considers intrinsic and extraneous cognitive load, is that the assumed increase in cognitive load can clearly be attributed to intrinsic cognitive load. However, an increase in task difficulty must also be considered for the two-factorial model of CLT, depending on the available cognitive capacity as a function of individual learner characteristics. Given a proper instructional design and considering established multimedia design principles, extraneous cognitive load can be assumed to be constant for both models of CLT. Concerning the measurement of cognitive load, methods of differentiated cognitive load measurement would be necessary, much like it holds true for the seductive details effect. Not only to gain insight into synergetic effects of instructional methods for fostering generative cognitive processes between the single cognitive load factors, but also in order to control for possible effects on task difficulty dependent on individual learner characteristics.

5. Empirical Studies

The present work comprises four studies that were designed to compare different methods of cognitive load measurement with regards to the theoretical changes of CLT (Choi et al., 2014; Kalyuga, 2011) and to the growing attention for learner characteristics. The first study (publication I) is focused on eye-tracking as a new technique to assess cognitive load while learning with multimedia learning instructions and the moderating influence of learners' prior knowledge and spatial ability on the seductive details effect. The second study (publication II) takes up the findings on eye movements as an indicator for cognitive activity of the first study and compares a total of four different measures of cognitive load, including eye movements, ICA, dual-task performance and subjective ratings. The third study (publication III) expands the moderation model of the first study to a model of moderated mediation considering learner characteristics as moderators and eye movements as a mediator for the seductive details effect. The fourth study (publication IV) finally compares the cognitive load measures used in the second study concerning their suitability for measuring the unique contributions of the single cognitive load factors to total cognitive load for separate manipulations of either extraneous or germane/intrinsic cognitive load.

5.1 Publication I: Do Learner Characteristics Moderate the Seductive Details Effect? A Cognitive Load Study using Eye Tracking (Park, Korbach, & Brünken, 2015)

Theoretical background

The study investigates the seductive details effect as a function of the learners' available cognitive capacity (Park et al., 2011) to explain contrasting results in seductive details research. The basic assumption is that seductive details are especially harmful when presented in cognitively high loading learning situations and for learners with low available cognitive capacity to process the additional irrelevant information. The study assumes prior knowledge and spatial ability as the relevant learner characteristics to determine the available amount of cognitive capacity for additional processing of seductive details. Several studies already showed the importance of the learners' prior knowledge for learning success (Kalyuga et al., 2003; Kalyuga et al., 1998; Koch, Seufert, & Brünken, 2008; McNamara, Klintsch, Songer, & Klintsch, 1996) and a study by Magner, Schwonke, Aleven, Popescu, and Renkel (2014) also showed a moderating influence of prior knowledge on learning success for learning with decorative illustrations. According to CLT (Plass et al., 2010; Sweller et al., 2011), prior knowledge affects intrinsic cognitive load as high prior knowledge in form of existing schemata can decrease element interactivity. In contrast to prior knowledge, spatial ability is not assumed to decrease element interactivity but instead to foster mental model construction. Several studies showed the advantages for high spatial ability learners concerning the construction of three-dimensional mental representations out of two-dimensional visual figural information (Mayer, 2001; Münzer et al., 2009) and for the processing of concurrent presentations of textual and corresponding pictorial information (Gyselinck et al., 2000; Mayer & Sims, 1994). The results of these studies support the assumption of a more efficient use of available cognitive capacity for high spatial ability learners especially when learning involves mapping of textual and pictorial representations. According to CLT and CTML (Mayer, 2001, 2005; Plass et al., 2010; Sweller et al., 2011), spatial ability can be assumed to reduce germane cognitive load as high spatial ability learners need less cognitive capacity for generative cognitive processing. In contrast to the following studies (publications II to IV), this study (publication I) considers only the three-factorial model of CLT and assumes changes to intrinsic cognitive load as relatively independent from changes to germane cognitive load, however the results will also be discussed with regard to the updated model of CLT (Choi et al., 2014; Kalyuga, 2011). With regard to the theoretical explanations for the seductive details effect, (1) cognitive overload, (2) diversion hypothesis, (3) disruption hypothesis or (4) distraction hypothesis (Rey, 2012), eye-tracking is used to analyze the learners' focus of attention and the cognitive activity that is spent on the processing of the relevant information (Mayer, 2010; Rayner, 1998). As several studies show an effect of prior knowledge on the learners' focus of attention and information selection (Canham & Hegarty, 2010; Haider & Frensch, 1999; Jarodzka et al., 2010), a moderating influence of prior knowledge on eye movements is also assumed for the seductive details effect. Concerning the integrative cognitive processes and the mapping of the corresponding textual and pictorial information, the learners' visual transitions between the related textual and pictorial information can be assumed to indicate cognitive engagement (Holsanova, Holmberg, & Holmqvist, 2009; Schmidt-Weigand et al., 2010). According to the theoretical assumptions, the goals of this study are to assess the moderating influence of prior knowledge and spatial ability on the seductive details effect with a decrease in learning performance and relevant information processing especially for low prior knowledge and low spatial ability learners.

Method

A sample of 50 participants (79.6% female, average age = 22.1 years, *SD* = 3.0) was randomly assigned either to the group that worked with the basic learning instruction (*N* = 25) or the group that worked with the seductive details learning instruction (*N* = 25). Separate analyses were conducted to assess the moderating effect of prior knowledge and spatial ability on the seductive details effect for learning success and for eye movements. All participants worked with a self-directed multimedia learning program concerning the ATP Synthase. The information was presented on eleven screens, where the first screen consisted only of textual information and all other screens presented both textual and corresponding pictorial information on the left side of the screen. Seductive details were presented on four of the eleven screens on the right side of the screen for the seductive details group (see Fig. 1).

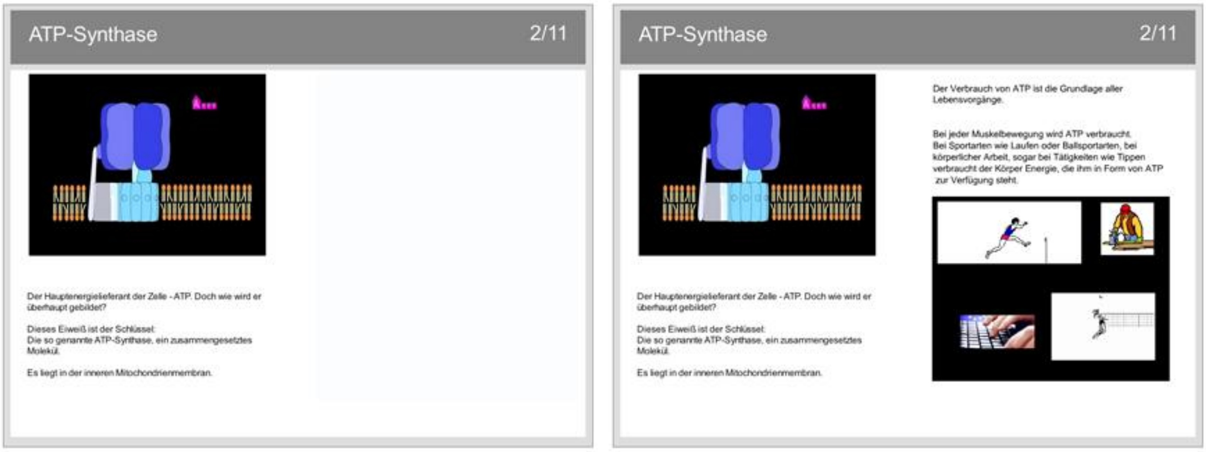

Figure 1. Example slide of the learning instruction with and without seductive details.

Working memory capacity was measured by the numerical memory updating subtest of Oberauer, Süß, Schulze, Wilhelm, and Wittmann (2000), time-on-task was registered automatically by the computer and participants' learning motivation was measured by a revised short version of the 100-item Inventory of School Motivation (ISM; McInerney & Sinclair, 1991) Cronbachs' α = 0.86, served as control measures. Prior knowledge was measured by a questionnaire that included five multiple-choice and eight open-ended questions, Cronbachs' α = 0.86. Spatial ability was measured by a standardized paper-folding and card-rotation test (Ekstrom, French, Harmann, & Dermen, 1976). Learning success was assessed by a learning performance test including the subscales retention and comprehension. The subscale retention included 5 items, 3 in multiple choice format and 2 in open response, showing a Cronbachs' α of 0.71 (item examples: (1) "The matrix is …" – the inside of the mitochondrium; the intermembrane space; a united cell structure in tissues; the space outside the mitochondrium; (2) Describe the term "proton-motive force"). The subscale comprehension included 7 items, 3 in multiple choice format and 4 in open response, showing a Cronbachs' α = 0.85 (item examples: (1) "What's the function of the ATP synthase's F0 complex?" – transport of protons into the matrix; transport of protons into the intermembrane space; the generation of proton-motive force; the formation of the proton gradient; (2)"Refer three requirements for the operational capability of the ATP synthase"). The participants' eye movements were recorded with a remote eye-tracking system (Tobii TX300) while participants worked on the learning program. The eye-tracking system is integrated in a 23 inch TFT (1929 x 1080 pixel) monitor and operates with a sample rate of 300 Hz. The areas of interest (AOI) were defined for the textual and pictorial information on the single screens. Participants' eye movements were analyzed using Tobii Studio software to calculate number and duration of fixations on the single AOIs. Total cognitive load was measured by subjective ratings (Paas, 1992) of task difficulty and mental effort on a 7 point Likert scale ("very low" to "very high") after screen 4 and 9 of the learning instruction.

Results

The two groups did not differ significantly concerning control and aptitude variables prior knowledge, $F(1, 48) = 1.07$, *n.s.*, spatial ability, $F < 1$, working memory capacity, $F < 1$, time-on-task, $F < 1$, or learning motivation, $F < 1$. The first screen of the learning program that shows only text and that is the same for all participants was used to control the variables of eye movement. There were no significant differences between the groups concerning the number of fixations or the total fixation duration, *F*s < 1. Independent samples t-tests were conducted for learning success, eye movement and cognitive load with the between subject factor seductive details (with vs. without) to first check the seductive details effect as prerequisite for the following moderation models. The results of the t-tests show a seductive details effect on comprehension, with lower comprehension performance for the seductive details group, $t(48) = 2.45$, $p = .009$, $d = .71$, but no effect on retention performance, $t(48) = .278$, *n.s.*. Furthermore, the results show an effect on the participants' eye movements, with a significant shorter total fixation duration on the relevant picture AOIs for the seductive details group, $t(43) = 1.806$, $p = .039$, $d = .55$, a significant smaller total number of fixations on the relevant picture AOIs, $t(43) = 2.234$, $p = .015$, $d = .68$ and a significant smaller number of transitions between the corresponding text and picture AOIs, $t(43) = 3.253$, $p = .001$, $d = .99$. Moreover, participants in the seductive details group fixated the relevant pictorial information significantly later than the group without seductive details, $t(42) = -2.412$, $p = .010$, $d = .74$. The subjective ratings of cognitive load show an effect of seductive details effect, $t(48) = 1.83$, $p = .036$, $d = .53$, with lower cognitive load ratings for learners of the seductive details group (see Table 1).

Table 1. Means and standard deviations for all dependent variables

	No Seductive Details (n = 25)	Seductive Details (n = 25)
	M (SD)	M (SD)
Comprehension (%)	64.24 (18.19)	47.88 (28.48)
Retention (%)	62.83 (18.33)	61.00 (27.50)
Cognitive load (max. = 7)	5.12 (.93)	4.44 (1.61)
Total fixation duration on the relevant pictures = Picture AOIs (sec.)	50.87 (33.87)	34.82 (25.31)
Total fixation count on the relevant pictures = Picture AOIs (N)	204.82 (158.25)	121.56 (81.28)
Transitions from relevant text to relevant picture = Transitions between text and picture AOIs (N)	23.67 (16.29)	11.50 (7.90)
Time to first fixation (sec.)	0.26 (0.31)	2.06 (3.49)

Note. *M* = Mean, *SD* = Standard Deviation.

Separate moderation analyses were conducted for prior knowledge and spatial ability either in combination with learning success or in combination with eye movements. All analyses are based on the regression-based approach for conditional process modeling by Hayes (2013). Only the comprehension performance was considered to analyze the moderating effects on learning performance because of the missing effect of seductive details on retention. To analyze the moderating effects on eye movements, the transitions between corresponding text and picture AOIs were chosen as dependent variable as these transitions are assumed to be a viable indicator of generative cognitive processing.

The first analysis assessed the moderating influence of spatial ability on comprehension performance. The regression model was significant, $F(3,45) = 2.8$, $R^2 = .16$, $p = .050$. In accordance with the result of the t-tests, the regression analysis shows a main effect for seductive details, $t(45) = -2.08$, $\beta = -1.11$, $p = .043$ but no main effect for spatial ability $t(45) = 1.37$, $\beta = 5.09$, *n.s.* and no interaction of spatial ability and seductive details $t(45) = .72$, $\beta = 2.65$, *n.s.*. The regression coefficients show marginal significant conditional effects for the 10th, the 25th and the 50th (but not for the 75th and 90th) percentiles of spatial ability, with $\beta = -1.66$, $p = .084$, $\beta = -1.41$, $p = .045$ and $\beta = -1.12$, $p = .043$, indicating that learners with low levels of spatial ability are more affected by seductive details (see Figure 2).

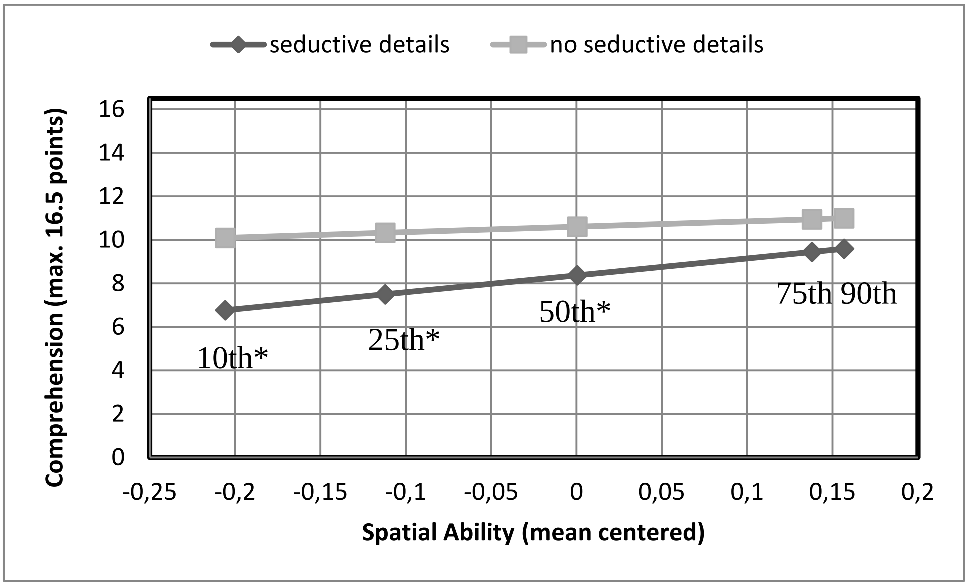

Figure 2. Comprehension performance moderated by spatial ability.

The second analysis assessed the moderating influence of prior knowledge on comprehension performance. The regression model was significant, $F(3, 46) = 3.8$, $R^2 = .20$, $p = .016$. In accordance with the result of the *t*-tests, the regression analysis shows a main effect for seductive details, $t(46) = -2.8$, $\beta = -1.53$, $p = .007$, a main effect for prior knowledge $t(46) = 2.08$, $\beta = .34$, $p = .042$ but no interaction of prior knowledge and seductive details $t(46) = .66$, $\beta = .11$, *n.s.*. The regression coefficients show marginal significant conditional effects for the 10th, the 25th, the 50th and the 75th (but not for the 90th) percentiles of prior knowledge, with $\beta = -1.98$, $p = .027$, $\beta = -1.87$, $p = .016$, $\beta = -1.65$, $p = .006$ and $\beta = -1.27$, $p = .065$, indicating that learners with low prior knowledge are more affected by seductive details (see Figure 3).

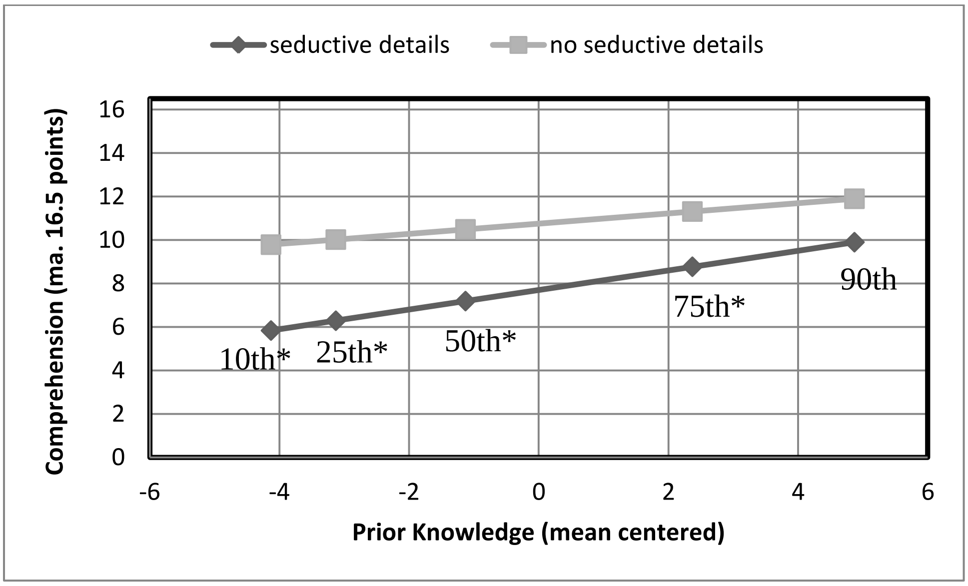

Figure 3. Comprehension performance moderated by prior knowledge.

The third analysis assessed the moderating influence of spatial ability on the number of transitions between corresponding text and picture AOIs. The regression model was significant, $F(3, 40) = 3.2$, $R^2 = .19$, $p = .034$. In accordance with the result of the *t*-tests, the regression analysis shows a main effect for seductive details, $t(40) = -3.07$, $\beta = -5.99$, $p = .003$ but no main effect for spatial ability $t(40) = -.50$, $\beta = -7.06$, *n.s.* and no interaction of spatial ability and seductive details $t(40) =.51$, $\beta = 7.36$, *n.s.*. The regression coefficients show marginal significant conditional effects for the 10th, the 25^{th}, the 50th and the 75th (but not for the 90th) percentiles of spatial ability, with $\beta = -7.46$, $p = .042$, $\beta = -6.77$, $p = .011$, $\beta = -5.94$, $p = .004$ and $\beta = -4.92$, $p = .081$, indicating that learners with low levels of spatial ability are more affected by seductive details (see Figure 4).

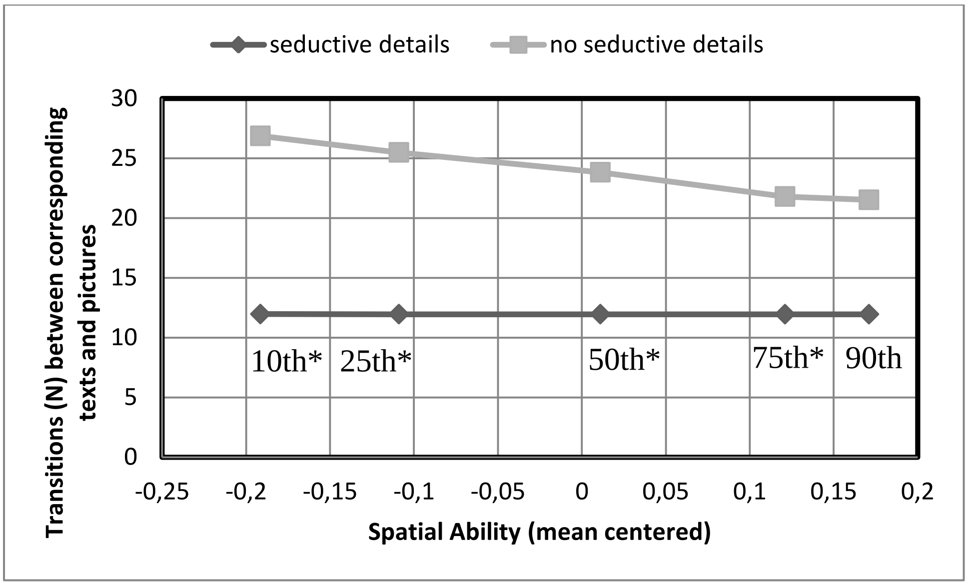

Figure 4. Transitions between text and picture AOIs moderated by spatial ability.

The fourth analysis assessed the moderating influence of prior knowledge on the number of transitions between corresponding text and picture AOIs. The regression model was significant, $F(3, 41) = 4.7$, $R^2 = .25$, $p = .006$. In accordance with the result of the *t*-tests, the regression analysis shows a main effect for seductive details, $t(41) = -3.01$, $\beta = -5.62$, $p = .004$ but no main effect for prior knowledge $t(41) = -1.66$, $\beta = -.94$, *n.s.*, no interaction of prior knowledge and seductive details $t(41) = .84$, $\beta = .48$, *n.s.*. The regression coefficients show marginal significant conditional effects for the 10th, the 25^{th}, the 50th and the 75th (but not for the 90th) percentiles of prior knowledge, with $\beta = 7.66$, $p = .014$, $\beta = 7.18$, $p = .008$, $\beta = 6.22$, $p = .003$ and $\beta = 4.55$, $p = .055$, indicating that learners with low prior knowledge are more affected by seductive details (see Figure 5).

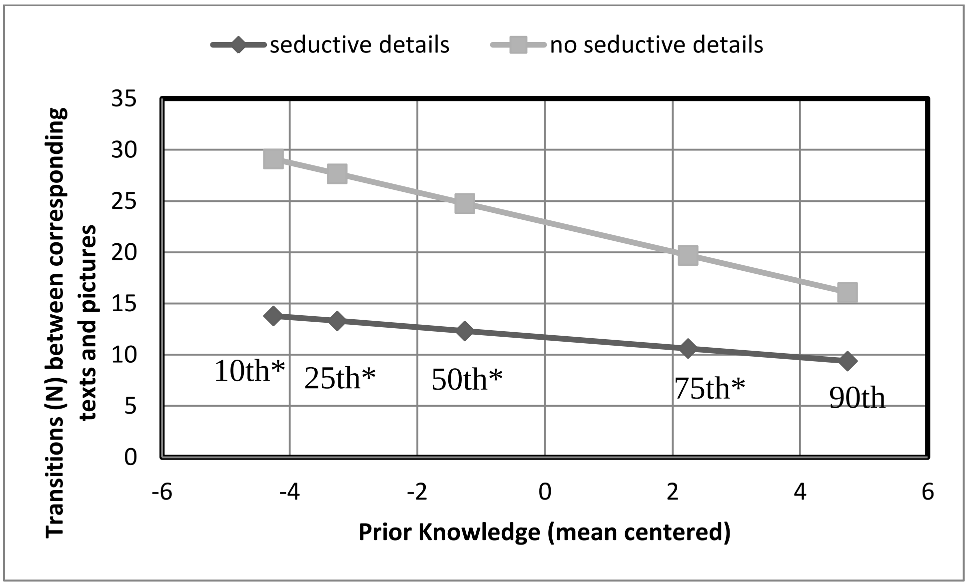

Figure 5. Transitions between text and picture AOIs moderated by prior knowledge.

Two additional moderation models were conducted to investigate a possible moderating influence of prior knowledge and spatial ability on the cognitive load ratings. The regression model for spatial ability was not significant, $F(3,45) = .82$, $R^2 = .05$, *n.s.*. The regression model for prior knowledge was significant, $F(3,46) = 5.3$, $R^2 = .26$, $p = .003$, with an effect for prior knowledge $t(46) = -3.28$, $\beta = -.17$, $p = .002$, indicating higher cognitive load for learners with low prior knowledge but no effect for seductive details, $t(46) = -1.5$, $\beta = -.26$, *n.s.*, no interaction effect, $t(46) = -.79$, $\beta = -.04$, *n.s.*, and no conditional effects of the moderator.

Summary and discussion

The results of publication I confirm the hypothesis concerning the detrimental effect of seductive details on learning performance and on visual information processing as well as the hypothesis concerning the moderating influence of prior knowledge and spatial ability. The results of the moderation models support the cognitive load explanation for the seductive details effect, as learners with low prior knowledge and low spatial ability were more affected in learning performance and visual information processing. The results further support the distraction hypothesis as especially the relevant pictorial information was fixated later, shorter and numerically less in comparison to the group without seductive details. The decrease in integrative transitions between corresponding text and picture information further supports the assumption that seductive details decreased generative cognitive processing. In sum, the analysis of eye movements show perfunctory information processing of the relevant information for the seductive details group. In contrast to the hypothesis, seductive details caused a decrease in perceived cognitive load. However in combination with the indicated perfunctory information processing of the relevant information, the results of the cognitive load ratings are in line with a decreased cognitive activity dedicated to achieve the learning objective. In accordance with the three-factorial model of CLT (Plass et al., 2010; Sweller et al., 2011), the results indicate a decrease in germane cognitive load, that means a decrease in intrinsic cognitive load for the two-factorial model of CLT (Choi et al., 2014; Kalyuga, 2011). Especially concerning the interpretation of the cognitive load ratings (Paas, 1992), the study shows the benefits of including eye-movement analysis for research on cognitive load as eye movements provide detailed information about the cognitive activity on visual information processing.

5.2 Publication II: Measurement of Cognitive Load in Multimedia Learning: A Comparison of Different Objective Measures (Korbach, Brünken, & Park, 2017)

Theoretical background

With regard to the results of the eye-movement analysis of publication I, the second study (publication II) was conducted to compare 4 different measures of cognitive load: (1) dual-task performance, (2) eye movements, (3) ICA and (4) subjective ratings. As cognitive load measurement is essential for research on CLT and learning, a special interest lies on methods that are objective, direct, reliable and measure cognitive load while it is occurring (Brünken et al., 2010). Recent studies by Leppink et al. (2013; 2014) and Leppink and van den Heuvel (2015) already demonstrated the possibility to differentiate between the single cognitive load factors and to assess them separately with subjective rating scales. Therefore, the goal of the second study (publication II) is not only to compare different measures of cognitive load but also to review the data from the objective measures concerning detailed information about cognitive processes that are unique to the single cognitive load factors. To this end, the study considers the former model of CLT (Plass et al., 2010; Sweller et al., 2011) with the factors intrinsic, extraneous and germane cognitive load as well as the updated model of CLT (Choi et al., 2014; Kalyuga, 2011) with the factors intrinsic and extraneous cognitive load. The rhythm method (Park & Brünken, 2015) —a rhythmic foot-tapping task without external cues — is used to assess the dual-task performance. The method is assumed to measure total cognitive load as the rhythm production relies on inhibition processes associated with executive control. The analysis of eye movements is based on fixations, as fixations proved to be reliable indicators for cognitive processing (Haider & Frensch, 1999; Jarodzka et al., 2010) and includes the analysis of transitions between corresponding text and picture AOIs as indicator for integrative cognitive processes (Park, Korbach, & Brünken, 2015, Schmidt-

Weigand et al., 2010). The pupillometric analysis is focused on the ICA (Marshall, 2007) and the rating scale by Paas (1992) is used for the subjective ratings of perceived cognitive load. The seductive details effect is used to vary cognitive load as seductive details are assumed to increase cognitive load due to additional irrelevant information processing. Given the results of the first study (publication I), which showed a decrease in relevant information processing and lower ratings of perceived cognitive load for the seductive details group, the second study will analyze the whole information processing including the additional irrelevant information processing for the seductive details group. Therefore, an increase in extraneous cognitive load is assumed for the seductive details group in combination with a decrease in generative cognitive processing (publication I) that is germane cognitive load for the former model of CLT (Plass et al., 2010; Sweller et al., 2011) and intrinsic cognitive load for the updated model of CLT (Choi et al., 2014; Kalyuga, 2011). Intrinsic cognitive load is assumed to be constant for the former model of CLT as seductive details can be processed independently from the learning objective and should not increase element interactivity. Overall, all cognitive load measures are assumed to indicate an increase in cognitive load due to additional irrelevant information processing. Moreover, the eye movements are assumed to indicate not only the overall increase in cognitive activity on information processing but also the unique contribution for relevant and irrelevant information processing.

Method

A sample of 50 participants (70% female, average age = 22.24 years, *SD* = 2.45) was randomly assigned to either the group that worked with the basic learning instruction (*N* = 25) or the group that worked with the seductive details learning instruction (*N* = 25). The learning instruction and the learning objective was the same as for the first study (publication I) and dealt with the ATP synthase enzyme. The information was again presented on 11 screens, of which the first screen consisted only of textual information and all other screens presented textual and corresponding pictorial information on the left side of the screen. Seductive details were presented on 4 of the 11 screens on the right side of the screen for the seductive details group (see Fig. 1). The difference to the first study was mainly the change from a self-directed to a system-paced multimedia learning instruction with fixed learning times per screen based on the empirically tested mean reading time for the seductive details version. According to the first study (publication I), the same measures were used to assess the control variables working memory capacity (Oberauer et al., 200), spatial ability (Ekstrom et al., 1976), the 100-item ISM (McInerney & Sinclair, 1991) Cronbach's $\alpha = 0.83$ and prior knowledge by a questionnaire including four multiple-choice items and seven open-ended questions, Cronbachs' $\alpha = 0.72$. The test for learning performance used the same items as in the first study (publication I) with a difficulty index of $.20 < p_i < .80$ and included the two subscales retention and comprehension. The retention scale consisted of 5 items, 3 in multiple-choice and 2 in open-ended response, Cronbach's $\alpha = 0.73$. The comprehension scale consisted of 7 items, 4 in multiple-choice and 3 in open-ended response, Cronbach's $\alpha = 0.75$. For the rhythm method analysis the precision of the performance was calculated as an individual's deviation from the mean rhythm values during the learning phase. The given rhythm was Tap-Tap-Pause-Pause and was divided for analysis into the short time interval between the Tap-Tap and the long time interval that included the Pause-Pause (for a detailed description see Park & Brünken, 2015). The separate scales for the short and long rhythm-component showed an excellent internal consistency with a Guttmans split-half coefficients of $r = .938$ for the short and $r = .929$ for the long rhythm component. The participants' eye movements were recorded with a remote eye-tracking system (Tobii TX300) while participants worked on the learning program. The eye-tracking system is integrated in a 23 inch TFT (1929 x 1080 pixel) monitor and operates with a sample rate of 300 Hz. The areas of interest (AOI) were defined for the relevant text and picture information as well as for the seductive details text and picture information on the single screens. Participants' eye movements were analyzed using EyeWorks^{TM}-analysis software to calculate number and duration of fixations on the single AOIs as well as the ICA values. The subjective ratings of perceived cognitive load (Paas, 1992) were used to assess cognitive load after screen 4 and after the last screen of the learning instruction and included one item for rating task difficulty and one item for rating mental effort on a 7 point Likert scale ("very low" to "very high").

Results

There were no significant group differences for the control variables spatial ability, $F(1, 48) = 1.20$, *n.s.*, prior knowledge, $F < 1$, working memory capacity, $F(1,48) = 2.71$, *n.s.* or learning motivation, $F < 1$. The first screen that was common for both groups showed further no group differences for ICA, fixation duration, the number of fixations or the long component of rhythm performance, all $Fs < 1$ but for the short component of the rhythm performance $F(1, 48) = 6.06$, $p = .017$, $\eta^2 = .12$. Therefore the short component was excluded from further analysis and only the long component was analyzed to assess rhythm performance. Learning performance and cognitive load measures were analyzed separately and the cognitive load measures were grouped with respect to their inter correlations. The MANOVA for learning performance confirms the seductive details effect, $F(3,46) = 4.42$, $p = .008$, $\eta^2 = .22$. Univariate testing shows a significant decrease in comprehension, $F(1,48) = 6.01$, $p < .05$, η^2

=.11, and retention, $F(1,48) = 8.82$, $p = .005$, $\eta^2=.16$, for the seductive details group (see Table 2).

Table 2. Means and standard deviations for learning performance

	No Seductive Details (n = 25) *M* (*SD*)	Seductive Details (n = 25) *M* (*SD*)
Comprehension (%)	62.86 (15.76)	49.28 (23.29)
Retention (%)	62.36 (20.28)	43.9 (23.65)

Note. *M* = Mean, *SD* = Standard Deviation.

The MANOVA for ICA, eye movements and subjective cognitive load ratings also confirms the seductive details effect, $F(23,20) = 43.81$, $p < .001$, $\eta^2 = .98$. Univariate testing shows a significant decrease of the total fixation duration on relevant picture AOIs for the seductive details group, $F(1,42) = 16.41$, $p < .001$, $\eta^2 = .28$ that is no longer present when the additional fixation duration on the seductive details AOIs is added to compare the total fixation duration across all picture AOIs, $F(1,42) = 2.77$, *n.s.*. The fixation duration on relevant text AOIs shows no significant difference between the groups, $F < 1$, however the analysis of fixation duration across all text AOIs shows a significant increase in overall text processing for the seductive details group, $F(1,42) = 6.37$, $p = .015$, $\eta^2= .13$. The total fixation duration across all text and picture AOIs shows no significant difference between the groups, $F(1,42) = 1.29$, *n.s* (see Table 3).

Table 3. Means and standard deviations for fixation duration

	No Seductive Details (n = 25) *M* (*SD*)	Seductive Details (n = 25) *M* (*SD*)
Total Fixation Duration on relevant Picture AOIs	78.26 (43.26)	36.00 22.86)
Total Fixation Duration on all Picture AOIs	78.26 (43.26)	59.29 (31.34)
Total Fixation Duration on relevant Text AOIs	164.35 (62.17)	151.84 (53.92)
Total Fixation Duration on all Text AOIs	164.35 (62.17)	211.99 (62.98)
Total Fixation Duration on all AOIs	242.61 (84.84)	271.28 (82.30)

Note. *M* = Mean, *SD* = Standard Deviation.

The number of fixations on the relevant picture AOIs shows a significant decrease for the seductive details group, $F(1,42) = 18.27$, $p < .001$, $\eta^2 = .30$, that is also no longer present when the additional fixations on the seductive details picture AOIs are added, $F < 1$. There is no significant difference in the number of fixations on relevant text AOIs, *F*(1,42) = 1.62, *n.s.*, across all text AOIs *F*(1,42) = 1.26, *n.s.*, or across all AOI's with text and pictures, *F* < 1 (see Table 4).

Table 4. Means and standard deviations for the number of fixations

	No Seductive Details (*n* = 25) *M* (*SD*)	Seductive Details (*n* = 25) *M* (*SD*)
Total Fixation Number on relevant Picture AOIs	150.41 (58.55)	87.14 (37.32)
Total Fixation Number on all Picture AOIs	150.41 (58.55)	146.95 (59.96)
Total Fixation Number on relevant Text AOIs	414.23 (209.37)	348.82 (118.92)
Total Fixation Number on all Text AOIs	414.2 (209.37)	473.00 (129.21)
Total Fixation Number on all AOIs	564.64 (222.66)	619.95 (174.09)

Note. *M* = Mean, *SD* = Standard Deviation.

The number of transitions between corresponding relevant text and picture AOIs show a significant decrease for the seductive details group, *F*(1,42) = 10.57, *p* = .002, η^2 = .20, adding the additional irrelevant transitions between the seductive details AOI's and between relevant and seductive details AOI's shows a significant increase in the total number of transitions for the seductive details group, *F*(1,42) = 5.45, *p* = .024, η^2 = .12 (see Table 5).

Table 5. Means and standard deviations for the number of transitions

	No Seductive Details (*n* = 25) *M* (*SD*)	Seductive Details (*n* = 25) *M* (*SD*)
Transitions between relevant AOI's (N)	30.73 (11.76)	19.45 (11.24)
Transitions between all AOI's (N)	30.73 (11.76)	41.45 (18.11)

Note. *M* = Mean, *SD* = Standard Deviation.

The ICA values show no significant differences between the groups for relevant picture AOIs, relevant text AOI's and all picture AOI's, all *Fs* < 1, all text AOI's, *F*(1,42) = 2.70, *n.s.* or the total ICA across all AOI's, *F* < 1. The subjective ratings of perceived cognitive load show no significant differences between the groups for the mental effort rating after screen 4, *F*(1,42) = 2.40, *n.s.*, and after screen 9, *F* < 1 or the ratings of task difficulty after screen 4 or screen 9, all *F's* < 1. The rhythm method shows a significant decrease in dual-task performance for the seductive details group, *F*(1,44) = 4.10, *p* < .049, η^2 = .09 with an increasing mean deviation from the performed rhythm (*M* = 141.68 msec., *SD* = 50.78 msec.) in contrast to the group without seductive details (M = 113.49 msec., SD = 43.32 msec.). Significant correlations between learning performance and cognitive load measures were found for the deviation in rhythm performance and comprehension, $r = -.48$, $p = .001$, as well as for retention, $r = -.35$, $p = .02$, the subjective ratings for task difficulty and comprehension after screen four, $r = -.48$, $p = .000$ and after the last screen of the learning instruction $r = -.32$, $p = .025$, the subjective ratings of task difficulty and retention after screen four, $r = -.46$, $p = .001$ and after the last screen of the learning instruction, $r = -.39$, $p = .005$, the number of fixations on the relevant text AOIs and comprehension, $r = .31$, $p = .040$, the number of fixations on the relevant picture AOIs and comprehension, $r = .37$, $p = .010$, the number of fixations on the relevant picture AOIs and retention, $r = .29$, $p = .046$, the fixation duration on relevant picture AOIs and retention, $r = .35$, $p = .016$ as well as for the number of relevant transitions and retention, $r = .29$, $p = .047$.

Summary and discussion

The results confirm the detrimental effect of seductive details on learning performance as well as on visual information processing and are in line with the results of the first study (Park et al., 2015). The results of the rhythm method (Park & Brünken, 2015) further indicate an increase in total cognitive load that was not measured by ICA or the subjective ratings of cognitive load. The overall increase in cognitive activity on information processing was only indicated by the analysis of the whole text processing and the total number of transitions across all AOI's that included additional irrelevant and non-integrative transitions between seductive details AOI's and between relevant and seductive details AOI's. However, the analysis of eye movements provides detailed information about the amount of cognitive activity dedicated to generative cognitive processing and the amount of cognitive activity dedicated to irrelevant cognitive processing for the seductive details group. Concerning the models of CLT, the results are in line with the former model of CLT (Plass et al., 2010; Sweller et al., 2011) and the updated model of CLT (Choi et al., 2014; Kalyuga, 2011) with a decrease in germane respectively intrinsic cognitive load indicated by a decrease in relevant information processing and an increase in extraneous cognitive load indicated by additional irrelevant information processing that causes an increase in total cognitive load and overall information processing. As the analysis of eye movements shows a synergetic effect between extraneous and germane respectively intrinsic cognitive load, the results suggest that seductive details did not provoke a cognitive overload but rather a redistribution of cognitive resources that is in line with the results of Rey (2012). That might further explain why the increase in total cognitive load was that small in the recent study and therefore difficult to measure, for example by the subjective ratings of perceived cognitive load (Paas, 1992).

5.3 Publication III: Learner Characteristics and Information Processing: A Moderated Mediation of the Seductive Details Effect (Korbach, Brünken, & Park, 2016)

Theoretical background

With regard to the results of the first and the second studies (publications I and II), this study investigates a model of moderated mediation for the seductive details effect. As eye movements turned out to be moderated by learner characteristics, to be affected by seductive details and to represent at least one observable part of cognitive processing, the results of these studies suggest a mediating function of eye movements on learning performance. Moreover, the indicated increase in total cognitive load from the second study (publication II) supports the assumption of a cognitive load involvement to explain the seductive details effect. Therefore, the recent study uses a 2x2 factorial design to further illuminate the involvement of limited cognitive capacity to explain the seductive details effect with seductive details (with/without) as a first factor and task condition (single/dual-task) as a second factor. The lowest cognitive load is assumed for the group without seductive details in the single-task condition and the highest cognitive load is assumed for the group with seductive details in the dual-task condition. The rhythm method (Park & Brünken, 2015) is used as secondary-task to increase the cognitive load in this study and by the way the influence of the additional cognitive load on learning success is investigated to review harmful effects of the rhythm method on learning performance. Prior knowledge and spatial ability are considered as relevant learner characteristics to moderate learning performance and visual information processing as in the first study (publication I). For the model of moderated mediation, task condition (single/dual-task) is set as a first moderator and prior knowledge or spatial ability is set as a second moderator (see Fig. 6).

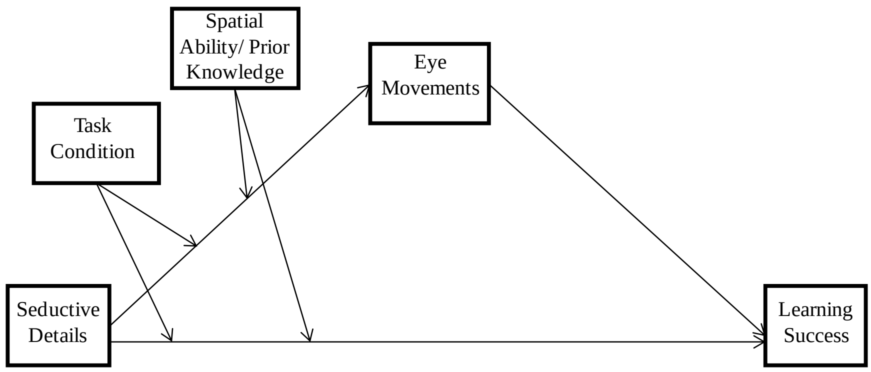

Figure 6. Conceptual model of the moderated mediation.

The study considers the former model of CLT (Plass et al., 2010; Sweller et al., 2011) with the factors intrinsic, extraneous and germane cognitive load as well as the updated model of CLT (Choi et al., 2014; Kalyuga, 2011) with the factors intrinsic and extraneous cognitive load. Seductive details and the secondary-task are both assumed to increase extraneous cognitive load by additional irrelevant cognitive processing. It is assumed that seductive details decrease learning success and visual information processing specifically in the cognitive high loading dual-task condition and that the seductive details effect is at first present to learners with low prior knowledge and spatial ability. Visual information processing is further assumed to mediate the seductive details effect on learning performance.

Method

A sample of 108 participants (74.1% female, average age = 23.09 years, *SD* = 3.3) was randomly assigned to the group that worked with the basic learning instruction in the single-task condition (*N* = 27), that worked with the basic learning instruction in the dual-task condition (*N* = 27), that worked with the seductive details learning instruction in the single-task condition (*N* = 27) or that worked with the seductive details learning instruction in the dual-task condition (*N* = 27). The learning instruction and learning objective used were the same as for the first and the second study (publications I & II) and dealt with the ATP synthase enzyme. The information was again presented on 11 screens, of which the first screen consisted only of textual information and all other screens presented textual and corresponding pictorial information on the left side of the screen. Seductive details were presented on 4 of the 11 screens on the right side of the screen for the seductive details group (see Fig. 1) and as in the second study time on task was controlled by pre-set learning times. Working memory capacity (Oberauer et al., 200) and learning motivation (McInerney & Sinclaire, 1991), *Cronbachs' α* = 0.86 served as control variables. Spatial ability was measured by a standardized test (Ekstrom et al., 1976) and prior knowledge was measured by a questionnaire that included four multiple-choice and seven open-ended questions, *Cronbachs' α* = 0.76. Learning success was assessed by a learning performance test with a total of 17 items that included the subscales retention with 5 items, 3 in multiple choice format and 2 in open response, *Cronbachs' α* of 0.71, comprehension with 7 items, 4 in multiple choice format and 3 in open response, *Cronbachs' α* = 0.73 and transfer with 5 items in open response format, *Cronbachs' α* = 0.72. The item difficulty of each item lies between *p* = .20 and *p* = .80. The participants' eye movements were recorded with a remote eye-tracking system (Tobii TX300) while they worked on the learning program. The eye-tracking system is integrated in a 23 inch TFT (1929 x 1080 pixel) monitor and operates with a sample rate of

300 Hz. Participants' eye movements were analyzed with EyeWorks[TM] software. The AOI's were defined for the relevant and seductive details text and picture information and the analysis of eye movements focused on the fixation duration and the transitions between the corresponding relevant text and picture AOI's. The subjective ratings of perceived cognitive load (Paas, 1992) were used to assess cognitive load after screen 4 and after the last screen of the learning instruction and included one item for rating task difficulty and one item for rating mental effort on a 7 point Likert scale ("very low" to "very high").

Results

The four groups did not differ significantly concerning the moderators prior knowledge, $F(3,104) = 1.644$, *n.s.*, and spatial ability, $F(3,104) = 1.637$, *n.s.* or concerning the control measures working memory capacity, $F(3,104) = 1.767$, *n.s.* or learning motivation, $F < 1$. The first screen of the learning program that is the same for all participants was used to control the variables of eye movement. There were no significant differences between the groups concerning the total fixation duration, $F(3,102) = 2.487$, *n.s.*. To assess the seductive details effect and the effect of task condition separate MANOVAs were conducted for learning success, cognitive load ratings and eye movements. Results for learning success show no effects of task condition, all *Fs* < 1, a significant seductive details effect on retention, $F(1,107) = 4.347$, $p < .05$, $\eta^2 = .040$ and comprehension, $F(1, 107) = 5.241$, $p < .05$, $\eta^2 = .048$, with a decrease in retention and comprehension performance for the seductive details groups but no effect on transfer, $F(1,107) = 2.865$, *n.s.* and no interaction effect for comprehension, $F(2,107) = 1.791$, *n.s.* or transfer, $F(2,107) = 2.07$, *n.s.*. However, a marginally significant interaction for retention, $F(2,107) = 3.054$, $p < .10$, $\eta^2 = .029$, indicates a decrease in retention when learning with seductive details under the cognitive high-loading dual-task condition (see Table 2). Results for the cognitive-load ratings show no effect of task condition on the ratings of mental effort $F(1,107) = 1.030$, *n.s.* and task difficulty $F < 1$. There was also no effect of seductive details on the ratings of mental effort and task difficulty, *Fs* < 1; moreover, no interaction was found for mental effort, $F < 1$ or task difficulty $F(2,107) = 1.093$, *n.s.* (see Table 6).

Table 6. Means and standard deviations for fixation duration

	Single Task Seductive Details (n=27) *M* (*SD*)	Single Task No Seductive Details (n=27) *M* (*SD*)	Dual Task Seductive Details (n=27) *M* (*SD*)	Dual Task No Seductive Details (n=27) *M* (*SD*)
Retention (%)	55.82 (25.40)	57.28 (19.10)	46.96 (24.90)	63.49 (19.10)
Comprehension (%)	55.56 (19.90)	59.00 (18.40)	49.04 (22.00)	62.21 (15.00)
Transfer (%)	42.60 (27.80)	27.50 (25.20)	34.00 (27.20)	31.83 (25.80)
Mental effort (max.7)	4.65 (1.23)	4.67 (.98)	4.87 (0.96)	4.58 (0.98)
Task difficulty (max.7)	4.24 (1.29)	4.44 (1.15)	4.33 (1.11)	4.09 (0.81)

Note. *M* = Mean, *SD* = Standard Deviation.

The analysis of eye movements show no effect of task condition for the total fixation duration on relevant picture AOIs, $F < 1$ but an effect of task condition for the relevant text AOIs $F(1,95) = 12.281$, $p < .01$, $\eta^2 = .118$. Marginally significant differences were found in transitions between related text and picture AOIs, $F(1,95) = 3.595$, $p < .10$, $\eta^2 = .038$, with an increase in total fixation duration for text AOIs and a decrease in relevant transitions under the cognitive high-loading dual-task condition in contrast to the low-loading single-task condition. There was an effect of seductive details for the total fixation duration on the relevant picture AOIs, $F(1,95) = 26.788$, $p < .01$, $\eta^2 = .246$, marginally significant differences concerning the relevant text AOIs, $F(1,95) = 3.862$, $p < .10$, $\eta^2 = .040$ and an effect for the number of relevant transitions between related text and picture AOIs, $F(1,95) = 31.564$, $p < .01$, $\eta^2 = .255$, with an overall decrease of relevant information processing for learners who learned with seductive details in comparison to learners learning without seductive details. No interaction was found between the factors seductive details and task condition for the total fixation duration on relevant picture AOIs, $F(2,95) = 1.866$, *n.s.*, the total fixation duration on the relevant text AOIs or the relevant transitions, *Fs* < 1 (see Table 7).

Table 7. Means and standard deviations for eye movements

	Single Task Seductive Details (*n*=27) *M* (*SD*)	Single Task No Seductive Details (*n*=27) *M* (*SD*)	Dual Task Seductive Details (*n*=27) *M* (*SD*)	Dual Task No Seductive Details (*n*=27) *M* (*SD*)
Total fixation duration on relevant picture AOIs (sec.)	47.16 (27.10)	74.66 (43.93)	34.39 (22.90)	81.62 (43.80)
Total fixation duration on relevant text AOIs (sec.)	87.61 (52.79)	121.10 (78.27)	141.17 (63.69)	158.93 (58.68)
Transitions between related text and picture AOIs (N)	23.76 (13.62)	38.83 (13.41)	18.68 (10.88)	33.74 (14.45)

Note. *M* = Mean, *SD* = Standard Deviation.

The regression-based approach for conditional process modelling by Hayes (2013) was used in order to assess the model of moderated mediation (see Figure 6). As only the total fixation duration on the relevant picture AOIs shows significant correlations for retention $r = .342$, $p < .01$, comprehension, $r = .348$, $p < .01$ and transfer, $r = -.207$, $p < .05$, this indicator of visual processing was considered as mediator for the seductive details effect. Separate moderated mediation analyses were conducted according to the subscales of learning performance and task condition served as a first and either prior knowledge or spatial ability as a second moderator. As the results for retention and comprehension performance are very similar, only the results for retention performance are reported. The first moderated mediation model was analyzed for retention performance and the moderators task condition and spatial ability (see Fig 7).

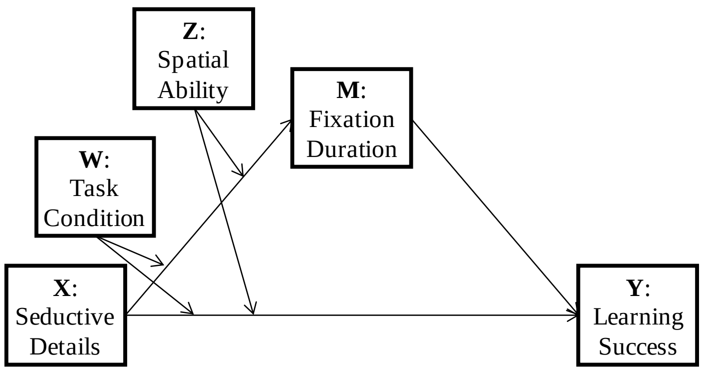

Figure 7. Mediation on retention moderated by task condition and spatial ability.

The conditional effects of seductive details on the direct path to retention at different values of the moderators were found only under the cognitive high-loading dual-task condition, especially for the 10th percentile, $t(96) = -2.59$, $\beta = -2.83$, $p < .05$, and the 25th percentile, $t(96) = -2.30$, $\beta = -2.10$, $p < .05$, of spatial ability. There were no differentiating moderating effects on the indirect path for the mediator. Overall, the model shows a full mediation of the seductive details effect by total fixation duration on the relevant picture AOIs and that a conditional direct effect with a decrease in learning success was only found for low spatial ability learners under the cognitive high-loading dual-task condition (see Table 8).

Table 8. Mediation on retention moderated by task condition and spatial ability

Path	*t*	*β*	*p*
X on Y	$t(96) = -1.07$	$\beta = -.61$	*n.s.*
X on M	$t(97) = -4.54$	$\beta = -32.28$	$p < .01$
M on Y	$t(96) = 2.43$	$\beta = .02$	$p < .05$
W/X on Y	$t(96) = -1.03$	$\beta =-1.1$	*n.s.*
W/X on M	$t(97) = -.88$	$\beta = -12.83$	*n.s.*
Z/X on Y	$t(96) = 2.47$	$\beta = 8.31$	$p < .05$
Z/X on M	$t(97) = -.12$	$\beta = -5.29$	*n.s.*

The second moderated mediation model was analyzed for transfer performance and the moderators task condition and spatial ability (see Fig 7). The conditional effects of seductive details on the direct path to transfer at different values of the moderators were found only under the cognitive low-loading single-task condition, especially for high spatial ability learners of the 50th percentile, $t(96) = 2.45$, $\beta = 1.08$, $p < .05$, the 75th percentile, $t(96) = 2.7$, $\beta = 1.35$, $p < .01$, and the 90th percentile, $t(96) = 2.71$, $\beta = 1.50$, $p < .01$, and under cognitive high-loading dual-task conditions for the 90th percentile, $t(96) = 2.01$, $\beta =1.06$, $p < .05$, of spatial ability. There were no differentiating moderating effects on the indirect path for the mediator. In sum, the model shows a partially mediation of the seductive details effect by total fixation duration on the relevant picture AOIs and a conditional direct effect with an increase in learning success for high spatial ability learners under the cognitive low-loading single-task condition as well as for learners with very high spatial ability under the cognitive high-loading dual-task condition (see Table 9).

Table 9. Mediation on transfer moderated by task condition and spatial ability

Path	t	β	p
X on Y	$t(96) = 2.45$	$\beta = .80$	$p < .05$
X on M	$t(97) = -4.54$	$\beta = -32.28$	$p < .01$
M on Y	$t(96) = 2.56$	$\beta = .01$	$p < .05$
W/X on Y	$t(96) = -.73$	$\beta = -.45$	*n.s.*
W/X on M	$t(97) = -.88$	$\beta = -12.83$	*n.s.*
Z/X on Y	$t(96) = 1.59$	$\beta = 3.05$	*n.s.*
Z/X on M	$t(97) = -.12$	$\beta = -5.29$	*n.s.*

The third moderated mediation model was analyzed for retention performance and the moderators task condition and prior knowledge (see Fig 8).

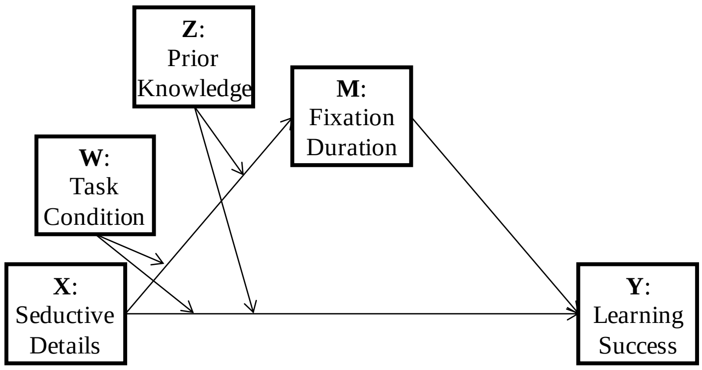

Figure 8. Mediation on retention moderated by task condition and prior knowledge.

The conditional effects of seductive details on the direct path to retention at values of the moderators show no moderating effects for task condition and prior knowledge. However, there were differentiating moderating effects on the indirect path for the mediator, as in 1000 bootstrap resamples and within a confidence interval of 95% the indirect effect did not significantly differ from zero at high levels of prior knowledge in the cognitive low-loading single-task condition for the 75th percentile, BootLLCI=-1.1363, BootULCI=.2344, and the 90th percentile, BootLLCI=-1.0758, BootULCI=.6208, as well as for high levels of prior knowledge in the cognitive high-loading dual-task condition for the 90th percentile, BootLLCI=-1.7862, BootULCI=.0088. In sum, the model shows a full mediation of the seductive details effect by total fixation duration on the relevant picture AOIs. There was no moderating influence of task condition or prior knowledge on the direct path to retention performance but a moderating influence of prior knowledge on the mediator, indicating a mediating effect of fixation duration especially for low prior knowledge learners in the cognitive high-loading dual-task condition (see Table 10).

Table 10. Mediation on retention moderated by task condition and prior knowledge

Path	t	β	p
X on Y	$t(96) = -1.40$	$\beta = -.83$	*n.s.*
X on M	$t(97) = -4.8$	$\beta = -32.23$	$p < .01$
M on Y	$t(96) = 3.00$	$\beta = .02$	$p < .01$
W/X on Y	$t(96) = -.89$	$\beta = -.98$	*n.s.*
W/X on M	$t(97) = -1.39$	$\beta = -20.20$	*n.s.*
Z/X on Y	$t(96) = .22$	$\beta =.06$	*n.s.*
Z/X on M	$t(97) = 1.54$	$\beta = 5.50$	*n.s.*

The fourth moderated mediation model was analyzed for transfer performance and the moderators task condition and prior knowledge (see Fig 8). The conditional effects of seductive details on the direct path to transfer at different values of the moderators were only found under the cognitive low-loading single-task condition and for low levels of prior knowledge, specifically the 10th percentile, $t(96) = 2.09$, $\beta = 1.06$, $p < .05$, and the 25th percentile, $t(96) = 2.12$, $\beta = .93$, $p < .05$. There were also differentiating moderating effects on the indirect path for the mediator, as in 1000 bootstrap resamples and within a confidence interval of 95% the indirect effect did not significantly differ from zero at high levels of prior knowledge in the cognitive low-loading single-task condition for the 75th percentile, BootLLCI=-.6512, BootULCI=.1075 and the 90th percentile, BootLLCI=-.5997, BootULCI=.33250, as well as for high levels of prior knowledge in the cognitive high-loading dual-task condition for the 90th percentile, BootLLCI=-.8706, BootULCI=.0223. Overall, the model shows a partial mediation of the seductive details effect by total fixation duration on the relevant picture AOIs. There was a moderating influence of task condition and prior knowledge, with an increase in transfer performance only for low prior knowledge learners in the cognitive low-loading single-task condition and a moderating influence of prior knowledge on the mediator, with a mediating effect of fixation duration especially for low prior knowledge learners in the cognitive high-loading dual-task condition (see Table 11).

Table 11. Mediation on transfer moderated by task condition and prior knowledge

Path	t	β	p
X on Y	$t(96) = 2.15$	$\beta = .66$	$p < .05$
X on M	$t(97) = -4.48$	$\beta = -32.23$	$p < .01$
M on Y	$t(96) = 3.24$	$\beta = .01$	$p < .01$
W/X on Y	$t(96) = -.27$	$\beta = -.15$	*n.s.*
W/X on M	$t(97) = -1.39$	$\beta = -20.20$	*n.s.*
Z/X on Y	$t(96) = -.94$	$\beta = -.13$	*n.s.*
Z/X on M	$t(97) = 1.54$	$\beta = 5.49$	*n.s.*

Summary and discussion

The results confirm the seductive details effect on learning performance as well as on visual information processing and are in line with results of the first and the second study (publication I & II). Furthermore, the results show that the rhythm method (Park & Brünken, 2015) which was used to measure cognitive load in the second study had no harmful effect on learning performance; however, the rhythm tapping increased visual information processing on the relevant text AOIs. The subjective cognitive load ratings (Paas, 1992) do not show differences in perceived cognitive load for seductive details or task condition. These results are in line with the assumption of a rather small increase in total cognitive load by each of the two factors. On the other hand, these results suggest in combination with the missing interaction effects for seductive details and task condition that the rhythm method was not sufficient to induce enough cognitive load to reach the learners' limits of cognitive capacity. The results of the moderated mediation models for retention and comprehension show that the visual information processing was only moderated by prior knowledge and not by spatial ability. These findings support the assumption that prior knowledge is especially important for information selection and attention direction (Canham & Hegarty, 2010; Haider & Frensch, 1999; Jarodzka et al., 2010). In contrast, a moderating influence of spatial ability and task condition was found for the direct effect of seductive details on retention and comprehension performance that supports the assumption of spatial ability as an important learner characteristic for mental model construction (Mayer, 2001; Münzer et al., 2009). In addition, the results suggest that cognitive capacity was more important for mental model construction than for information selection as the models of moderated mediation show moderating effects for task condition especially in combination with spatial ability. Concerning the moderated mediation models for transfer performance, the results suggest that low prior knowledge learners paid so much attention to the seductive details that there was a beneficial effect for some of the transfer questions. High spatial ability learners might have profited from the seductive details in a similar way but due to their efficient use of cognitive capacity for mental model construction. However, the results can be explained within CLT, the limited capacity assumptions and the increased cognitive load due to irrelevant information processing as only the high capacity learners showed beneficial effects in low loading single task conditions. Overall, the results are in line with the former model of CLT (Plass et al., 2010; Sweller et al., 2011) as well as with the updated model of CLT (Choi et al., 2014; Kalyuga, 2011). The results further underline the importance of individual learner characteristics not only concerning the emerging total cognitive load but also concerning the contribution of the different load factors. Thereby low prior knowledge learners seem to be specifically challenged in information selection and attention guidance whereas low spatial ability learners seem to be specifically challenged in information organization and integration. Eye-tracking again proved to be a valid method to measure cognitive activity — however only for that part of cognitive activity which is based on visual information processing and attention direction and which is readily observable.

5.4 Publication IV: Differentiating Different Types of Cognitive Load: A Comparison of Different Measures (Korbach, Brünken, & Park, 2017)

Theoretical background

With regard to the first three studies (publication I-III), the fourth study was designed to compare different methods of cognitive load measurement concerning their sensitivity for germane (Plass et al., 2010; Sweller et al., 2011) respectively intrinsic (Choi et al., 2014; Kalyuga, 2011) cognitive load manipulations. As the decrease of extraneous cognitive load is the primary goal of learning instructions that were designed according to CLT, the first three studies focused on the effects of an increase in extraneous cognitive load on learning performance and visual information processing. Furthermore, the studies tested methods to measure the increase in cognitive load due to extraneous cognitive load manipulations and possibilities to differentiate between unique contributions of cognitive processes to single cognitive load factors. Thereby, especially the second study (publication II) shows the benefits to use a combination of different measures to assess cognitive load and to identify related cognitive processes. The recent study will use the same methods (1) dual-task performance, (2) eye movements, (3) ICA and (4) subjective ratings to measure cognitive load for a learning instruction that fosters generative processing. An experimental three group design is used with mental animation prompts (Park et al., 2016) to increase germane respectively intrinsic cognitive load by fostering generative cognitive processing, seductive details to increase extraneous cognitive load by additional irrelevant information processing and a control group without mental animation prompts or seductive details. The different cognitive load measures are assumed to indicate an increase in cognitive load for both experimental groups in combination with an increase in cognitive activity on the visual information processing. The allocation of attention is assumed to indicate an increase in cognitive activity via the processing of additional irrelevant information together with a decrease in cognitive activity for the processing of the learning objective for the seductive details group (publication II). In contrast, the allocation of attention is assumed to indicate an increase in cognitive activity that leads to an increase in learning performance for the mental animation group. The eye movements that are assumed to indicate an increase in generative cognitive processing for the mental animation group are the transitions between corresponding text and picture AOIs (Schmidt-Weigand, Kohnert, & Glowalla, 2010) and the fixation duration on relevant picture AOIs (Mayer 2010; Park, Knörzer, Plass, & Brünken, 2015; Park, Korbach, & Brünken, 2015; Rayner et al., 2007; Reichle et al., 2003). Both kinds of eye movements are assumed to indicate mapping activity between textual and pictorial representations, activity on mentally animating mental representations and engagement in mental model construction.

Method

A sample of 78 participants (69.2% female, average age = 23.14 years, *SD* = 2.86) was randomly assigned to the group that worked with the basic learning instruction (*N* = 26), that worked with the seductive details learning instruction (*N* = 26) or that worked with the mental animation learning instruction (*N* = 26). The learning instruction and the learning objective used were the same as for the first through third studies (publication I-III) and dealt with the ATP synthase enzyme. The information was again presented on 11 screens, thereby the first screen consisted only of textual information and all other screens presented textual and corresponding pictorial information on the left side of the screen. Seductive details were presented on 4 of the 11 screens on the right side of the screen for the seductive details group (see Fig. 1). For the mental animation group the seductive details were replaced by mental animation prompts on the same screens (see Fig. 9) and as in the second study time on task was controlled by pre-set learning times.

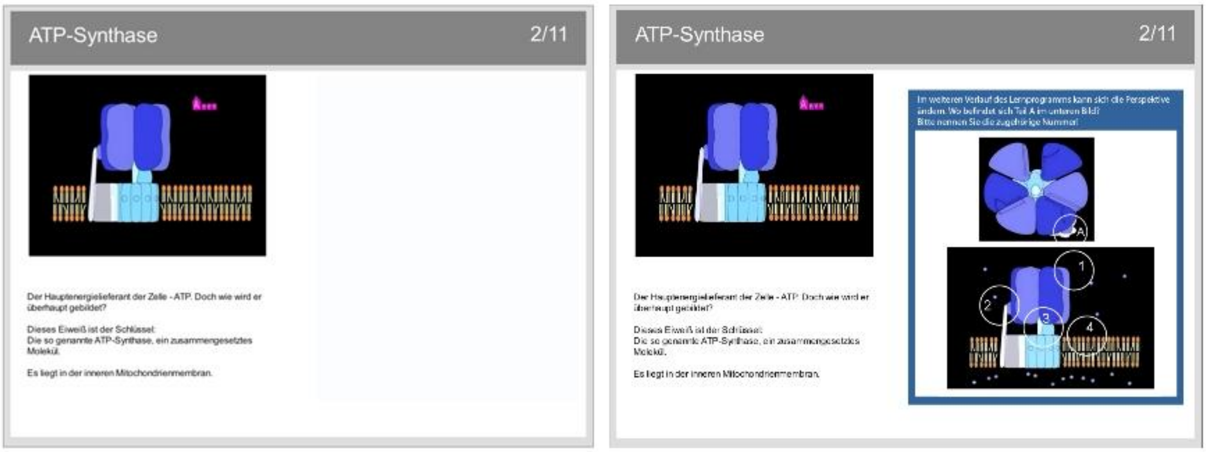

Figure 9. Example slide of the learning instruction with and without mental animation prompts.

Working memory capacity (Oberauer et al., 200) and learning motivation (McInerney & Sinclaire, 1991), *Cronbachs' α* = 0.85 served as control variables. Spatial ability was measured by a standardized test (Ekstrom et al., 1976). Prior knowledge was measured by a questionnaire that included four multiple-choice and seven open-ended questions, *Cronbachs' α* = 0.74. Learning success was assessed by a learning performance test with a total of 17 items that included the subscales retention with 5 items, 3 in multiple choice format and 2 in open response, *Cronbachs' α* of 0.67, comprehension with 8 items, 4 in multiple choice format and 4 in open response, *Cronbachs' α* = 0.71 and transfer with 5 items in open response format, *Cronbachs' α* = 0.73. The item difficulty of each item lies between $p = .20$ and $p = .80$. For the rhythm–method analysis, the precision of the performance was calculated as an individual's deviation from the mean rhythm values during the learning phase (for a detailed description see Park & Brünken, 2015). The analysis of rhythm performance was conducted for the long rhythm component with a Guttmans split-half coefficients of $r = .96$. The participants' eye movements were recorded with a remote eye-tracking system (Tobii TX300) while they worked on the learning program. The eye-tracking system is integrated in a 23 inch TFT (1929 x 1080 pixel) monitor and operates with a sample rate of 300 Hz. Participants' eye movements were analyzed with EyeWorks^{TM} software. The AOI's were defined for the relevant and the seductive details text and picture information as well as for the mental animation text and picture information. The analysis of eye movements focused on the fixation duration on text and picture AOIs and the transitions between the corresponding text and picture AOI's, including irrelevant transitions between non-related text and picture AOIs for the seductive details group. The index of cognitive activity (ICA) introduced by Marshall (2007) was automatically calculated by EyeWorksTM analysis software in accordance to the analysis for fixations. The subjective ratings of perceived cognitive load (Paas, 1992) were used to assess cognitive load after screen 4 and after the last slide of the learning instruction and included one item for rating task difficulty and one item for rating mental effort on a 7 point Likert scale ("very low" to "very high").

Results

The groups did not differ significantly concerning spatial ability, $F(2,75) = 1.031$, *n.s.*, prior knowledge, $F(2,75) = 1.089$, *n.s.*, working memory capacity, $F(2,75) = 2.971$, *n.s.* or learning motivation, $F < 1$. The first slide of the learning program which was identical for all groups showed no significant differences between the groups concerning fixation duration, $F(2,75) = 2.638$, *n.s.*, ICA, $F(2,75) = 2.094$, *n.s.* or the deviation in rhythm performance, $F(2,75) = 1.196$, *n.s.*. However, there was a significant difference for age, $F(2,75) = 5.710$, $p < .01$, η^2

=.132 between the mental animation group (*M* = 24.58, *SD* = 2.96), the seductive details group (*M* = 22.65, *SD* = 2.63) and the control group (*M* = 22.19, *SD* = 2.43). Because of significant correlations for age and several dependent cognitive load measures age was set as covariate for the following MANCOVA and the included analysis of contrasts will compare the mental animation group with the seductive details group and the control group. The MANCOVA was conducted for all dependent variables and the results show a significant effect for learning instruction, $F(24,128) = 3.520$, $p < .01$, $\eta^2 = .398$, and no effect for the covariate age, $F(12,63) = 1.516$, *n.s.*. The analyses of contrasts for learning performance shows a significantly higher transfer performance for the mental animation group in contrast to the control group, $\Delta M = -1.06$, $p = .029$ and a significantly higher comprehension performance , $\Delta M = -1.79$, $p = .017$ and transfer performance, $\Delta M = -.97$, $p = .039$, in contrast to the seductive details group (see Table 8).

Table 12. Means and standard deviations for learning performance

	With Mental Animation (*n* = 26) *M* (*SD*)	With Seductive Details (*n* = 26) *M* (*SD*)	Basic Instruction (*n* = 26) *M* (*SD*)
Comprehension (%)	54.99 (20.52)	43.16 (21.26)	56.98 (15.26)
Retention (%)	55.36 (19.65)	45.06 (22.09)	63.19 (20.79
Transfer (%)	44.55 (28.57)	32.69 (26.97)	32.37 (26.18)

Note. *M* = Mean, *SD* = Standard Deviation.

The analyses of contrasts for the rhythm method shows a significantly higher deviation for the mental animation group in contrast to the control group, $\Delta M = -41.765$, $p = .017$. The analyses of contrasts for the subjective ratings of perceived cognitive load show significantly higher cognitive load values for the mental animation group in contrast to the control group for the rating of task difficulty after screen 4, $\Delta M = -.677$, $p = .020$ and after screen 11, $\Delta M = -.633$, $p = .045$, as well as for the rating of mental effort after slide 11, $\Delta M = -.596$, $p = .040$.

Furthermore, the rating of task difficulty show significantly higher cognitive load values for the mental animation group in contrast to the seductive details group after screen 4, $\Delta M = -.585$, $p = .039$, and ratings of mental effort after screen 4, $\Delta M = -.744$, $p = .022$ and after screen 11, $\Delta M = -.638$, $p = .025$. The analyses of contrasts for the ICA values shows no significant differences between the groups (see Table 13).

Table 13. Means and standard deviations for cognitive load measures

	With Mental Animation (*n* = 26) *M* (*SD*)	With Seductive Details (*n* = 26) *M* (*SD*)	Basic Instruction (*n* = 26) *M* (*SD*)
Rhythm Method	173.80 (74.61)	149.64 (54.38)	119.03 (44.45)
Mental Effort (t1)	5.46 (1.10)	4.65 (1.06)	5.00 (1.13)
Mental Effort (t2)	5.42 (0.90)	4.77 (0.99)	4.81 (0.98)
Task Difficulty (t1)	4.85 (1.01)	4.00 (1.20)	3.85 (0.83)
Task Difficulty (t2)	5.08 (1.05)	4.31 (1.01)	4.19 (1.17)
ICA	0.477 (0.205)	0.431 (0.202)	0.449 (0.208)

Note. *M* = Mean, *SD* = Standard Deviation.

The analyses of contrasts for eye movements shows a significantly higher number of transitions for the mental animation in contrast to the control group, $\Delta M = -16.243$, $p = .003$, a significantly longer total fixation duration on picture AOIs in contrast to the seductive details group, $\Delta M = -36.802$, $p = .001$ and a significantly shorter total fixation duration on text AOIs, $\Delta M = 67.255$, $p = .000$ (see Table 14).

Table 14. Means and standard deviations for eye movements

	With Mental Animation (*n* = 26) *M* (*SD*)	With Seductive Details (*n* = 26) *M* (*SD*)	Basic Instruction (*n* = 26) *M* (*SD*)
Fixation Duration on MA/SD Picture AOIs (s)	47.50 (23.84)	20.33 (10.39)	- -
Fixation Duration on common Picture AOIs (s)	47.54 (33.63)	42.31 (23.78)	84.67 (38.11)
Total Fixation Duration on Picture AOIs (s)	95.04 (38.79)	62.64 (28.70)	84.67 (38.11)
Fixation Duration on MA/SD Text AOIs (s)	28.78 (16.62)	65.75 (30.48)	- -
Fixation Duration on common Text AOIs (s)	144.51 (48.65)	173.64 (45.93)	204.45 (71.23)
Total Fixation Duration on Text AOIs (s)	173.29 (59.37)	239.39 (37.18)	204.45 (71.23)
Number of MA/SD Transitions (N)	27.23 (15.46)	14.73 (7.45)	- -
Number of common Transitions (N)	13.35 (8.30)	17.00 (12.70)	25.46 (12.75)
Total Number of Transitions (N)	40.58 (22.07)	31.73 (17.84)	25.46 (12.75)

Note. *M* = Mean, *SD* = Standard Deviation.

The correlations between learning performance and cognitive load measures and especially between learning performance and the eye movements were analyzed in order to identify indicators for cognitive processes related to single cognitive load factors. The first analysis was conducted for the control group (N=26) and the correlations show a significant relation for the rating of task difficulty after slide 4 and comprehension, r = -.436, p =.026, and for the rating of mental effort after slide 11 and comprehension, r = -.427, p =.030, with a decrease in learning success and an increase in cognitive load. The total fixation duration on common relevant text AOIs show a significant relation to comprehension, r = -.422, p =.032 and the total fixation duration on common relevant picture AOIs show a significant relation to comprehension, r = .525, p =.006 and retention, r = .475, p =.014, with a decrease in eye movements for text AOIs and an increase in learning success, as well as an increase in eye movements for picture AOIs and an increase in learning success. For the seductive details group (N=26), the correlations show a significant relation for the rating of task difficulty after slide 4 and comprehension, r = -.441, p =.024, as well as for retention, r = -.507, p =.008 and for the rating of task difficulty after slide 11 and retention, r = -.479, p =.013, with a decrease in learning performance and an increase in the rated task difficulty. The eye movements show a significant relation between the total fixation duration on common relevant picture AOIs and retention, r = .412, p =.037, with an increase in eye movements and an increase in learning success. For the mental animation group (N=26), the correlations show only a significant relation for the rating of task difficulty after slide 4 and comprehension, r = -.492, p =.011, with a decrease in learning performance and an increase in the rated task difficulty.

Summary and discussion

The fourth study confirms the results for the seductive details effect of the first three studies (publication I-III). Furthermore, the results show a beneficial effect for the mental animation prompts together with an increase in cognitive load. The increase in cognitive load was measured by rhythm method (Park & Brünken, 2015) and the subjective ratings of perceived cognitive load (Paas, 1992) but not by the ICA (Marshall, 2007). The eye movements also indicate an increase in cognitive activity on total information processing and confirm the synergetic effect between relevant and irrelevant information processing for the seductive details group, with an increase in extraneous cognitive load and a decrease in germane respectively intrinsic cognitive load. For the mental animation group, the increase in additional relevant information processing is indicated by a significant increase in transitions in contrast to the control group and a significant increase in transitions and in picture fixation duration in contrast to the seductive details group. These results are in line with the theoretical assumptions concerning an increase in mapping activity between textual and pictorial representations, activity on mentally animating mental representations and engagement in mental model construction (Mayer 2010; Park, Knörzer, Plass, & Brünken, 2015; Park, Korbach, & Brünken, 2015; Rayner et al., 2007; Reichle et al., 2003; Schmidt-Weigand et al., 2010). However, the positive correlations between learning performance and the eye movement indicators are missing in the mental animation group in contrast to the control and the seductive details group. Whereas the effect of seductive details on visual processing and related cognitive processing can be explained as well with the former three-factorial model of CLT (Plass et al., 2010; Sweller et al., 2011) and the recent two-factorial model (Choi et al., 2014; Kalyuga, 2011), the effect of mental animation prompts rather supports the recent two-factorial model. On the one hand, the assumption that the element interactivity was indeed increased by raising the number of active elements in working memory for the mental animations group seems logical. On the other hand, the analysis of eye movements suggests that not all transitions between related information and all fixations on picture AOIs were beneficial for learning. Furthermore, it must be assumed that at least a part of these eye movements were due to cognitive processes of information search or necessary to keep all relevant information elements up in working memory as fostered by the mental animation prompts. The results for the subjective ratings further support the assumption that the increase in generative cognitive processing was closely related to an increase in task difficulty. As the mental animation prompts are designed to specifically foster the acquisition of process oriented knowledge (Park et al., 2016), focus was on the comprehension and transfer performance being assumed to be improved for the mental animations group. The missing results for comprehension performance and the descriptive decrease in retention performance in contrast to the control group might be due to a massive increase in total cognitive load and a close entanglement of task difficulty and generative cognitive processing.

6. Discussion and Future Directions

Concerning the first goal of the present dissertation — that is, to compare and to validate different methods of cognitive load measurement — the studies show differences between the results of the single methods. The rhythm method that was used as measure of secondary-task performance shows valid results for the extraneous (publication II) as well as for the germane/intrinsic cognitive load manipulation (publication IV). Thereby, high cognitive load is indicated by low secondary-task performance. However, the rhythm method is not suitable to differentiate between single cognitive load factors as the method shows sensitivity to both cognitive load manipulations. The general sensitivity of dual-task methodology is in line with the theoretical assumptions of a common and limited source of cognitive capacity for learning and secondary-task performance (Baddeley, 1986; Brünken et al. 2003). The overall correlations between secondary-task performance and learning success indicate that learning is in general hampered at high levels of cognitive load. However, the detailed correlation analysis for the mental animation prompts (publication IV) and the missing correlations for the mental animations group support the assumption that the increase in cognitive load was to some extent beneficial to learning. Overall, the rhythm method indicates a decrease of available cognitive capacity for secondary-task performance that can further be assumed to be caused by an increase in cognitive load due to the variations of the instructional design. The results further support the CLT’s limited capacity assumption and the assumption that total cognitive load can be raised by cognitive processing that causes additional extraneous as well as additional germane/intrinsic cognitive load.

The analysis of eye movements also proved to be a useful method for cognitive load research. However, the high cognitive load indicated by rhythm method is only shown by the total number of transitions between all available AOIs. In contrast to the rhythm method, the analysis of eye movements allows assumptions about the cognitive processes related to single cognitive load factors. For the seductive details learning instruction (publications I to IV), the eye movements show perfunctory information processing of the learning objective with a decrease in relevant picture fixation duration. In combination with the results of the rhythm method, high cognitive load and low learning success can be explained by a decrease in relevant information processing (germane/intrinsic) due to an increase in irrelevant information processing (extraneous). Of course in this case the detailed analysis is possible because of the nature of the instructional design and the seductive details effect as relevant and irrelevant information processing was clearly observable. For the mental animation prompts, the analysis was much more difficult and shows the limitations of eye-tracking methodology because in this case all observable information processing was in general relevant but not necessarily beneficial for learning and there was no possibility to further differentiate single cognitive processes. In sum, the results support the assumption of eye movements as an indicator for cognitive activity (Canham & Hegarty, 2010; De Koning, Tabbers, Rikers, & Paas, 2010). Especially the fixation duration on the relevant picture information that shows overall positive correlations for learning success can be assumed to be a valid indicator for cognitive load when learning with multimedia learning instructions (Mayer 2010; Rayner et al., 2007; Reichle et al., 2003). The overall number of transitions showed no explicit correlation pattern across all studies (publications I to IV), however there were positive correlations between the number of integrative transitions and learning success for the seductive details learning instruction (publications I and II). In general, the number of transitions can be assumed to indicate engagement in information processing and cognitive activity that is comparable to the results of the rhythm method. However, there were no correlations between the number of transitions and secondary-task performance. For the integrative transitions between corresponding text and picture information, the number of transitions can further be assumed to indicate the learning relevant engagement in mental model construction (Schmidt-Weigand et al., 2010). However, this might only be true for instructional designs that allow a clear differentiation between integrative and misleading transitions (Johnson & Mayer, 2012).

The ICA (Marshall, 2007) did not show any sensitivity to the cognitive load manipulations across all studies (publications I to IV) as there were no significant differences indicated between the different instructional designs nor plausible correlations to learning success or the other cognitive load measures. Especially the second study (publication II) focused on the analysis of ICA values and also checked the single AOIs for effects of illumination. Therefore, dependent sample t-tests were conducted to compare the ICA values of relevant and seductive details AOIs showing no significant differences between the different AOIs. However, the descriptive values indicate constant higher ICA values for text than for picture information. According to these results, this effect was investigated for the first three seconds after stimulus onset showing significant differences between text and picture information even for the first second after stimulus onset. In line with the study of Debue and van de Leemput (2014), the results of the present studies (publications II to IV) give no support for the sensitivity of the ICA to changes in cognitive load due to different instructional designs and question the usability of the ICA for multimedia learning instructions. Moreover, if differences between text and picture must be considered that rely basically on the presentation mode the ICA should be carefully used to investigate multimedia design principles.

The subjective ratings of perceived cognitive load (Paas, 1992) show relatively consistent results across all studies (publications I to IV); however, the results differ between the single studies. The first study shows a significant lower perceived cognitive load for the seductive details group in contrast to the control group. Cognitive load was analyzed as a combined rating out of the mental effort and task difficulty ratings close to the middle and after the learning instruction in this study. Given the timing effects for cognitive load ratings (Schmeck et al., 2015; Van Gog et al., 2012) with significant differences between immediate and delayed ratings, the single ratings of task difficulty and mental effort were analyzed separately for the following studies. However, the indicated low cognitive load in the first study was mainly based on low mental effort ratings. In contrast to this, the second and the third study show no significant differences in perceived task difficulty or mental effort between the seductive details and the control version of the learning instruction. As these studies show no increase in task difficulty, the results are in line with the theoretical assumption that seductive details do not increase task complexity as a function of the total number of information elements and that the interactivity between corresponding elements is the important factor for an increase in task difficulty. Furthermore, the results are in line with the analysis of eye movements that indicate a decrease of relevant information processing (intrinsic/germane) together with a small increase in total information processing due to additional irrelevant information processing (extraneous). In combination, the results of rhythm method, eye-movement analysis and subjective ratings suggest a small increase in total cognitive load that was probably not introspected by the learners because of the synergetic effect between the single cognitive load factors. One difference between the first and the following studies is the pre-set learning time for the second, the third and the fourth study. The significant difference in cognitive load of the first study (publication I) supports the assumption of perfunctory information processing of the learning objective. Moreover, the results suggest that the seductive details effect was especially harmful in the self-paced version of the learning instruction as the learners' only rated significant lower cognitive load in this study. Finally the fourth study shows an increase in cognitive load for the mental animation group that is indicated by the ratings of task difficulty as well as by the ratings of mental effort. In combination the results of rhythm method, eye-movement analysis and subjective ratings suggest a strong increase in total cognitive load due to an increase in element interactivity and a high engagement in information processing that was introspected by the learners. Thereby not all the observable information processing might have been useful and the total amount of cognitive load can be assumed as close to the individual capacity limits. Taking this into account, the results and the overall negative correlations between the ratings of task difficulty and learning success further support the assumption that learners are able to validly rate the amount of cognitive load that is based on task complexity (Ayres, 2006). However, the results show that it might be difficult for learners to introspect all cognitive processes and to differentiate between cognitive processes that are related to single cognitive load factors. Therefore, the results also support criticism on the quality criteria (Brünken et al., 2003; Brünken et al., 2010; Clark & Clark, 2010; Moreno, 2006). Especially the ratings of mental effort seem to be critical because the missing correlations to learning success indicate that several cognitive processes are confounded within this item and it might be difficult to distinguish general cognitive engagement, generative cognitive processing and misleading cognitive activity.

In sum, the rhythm method (Park & Brünken, 2015) is the only method that validly indicates the increase in total cognitive load for both kinds of cognitive load manipulation (publications II and IV). However, the method comes with several disadvantages as the secondary-task induces additional cognitive load by itself, the method is difficult to use and the analysis of secondary-task performance is comparatively difficult in contrast to the other methods. Furthermore, the method is not suitable for testing groups due to a high technical complexity and the secondary-task performance allows no conclusions about unique contributions of single cognitive load factors to total cognitive load. In contrast, the analysis of eye movements is less intrusive and provides the possibility to differentiate between learning relevant and irrelevant cognitive activity. The transitions, however, were the only indicator to show an increase in total cognitive activity and the relation between transitions and cognitive load needs further validation. The ICA (Marshall, 2007) showed no sensitivity to the cognitive load manipulation in the available studies and its suitability for the use in combination with multimedia learning instructions is questionable and needs further validation. The method of subjective rating scales for perceived cognitive load is generally promising. However, the ratings used (Paas, 1992) show at least a lack of sensitivity for the method and problems concerning validity for the mental effort ratings. Further research should investigate multidimensional rating scales for differentiating measurement of the single cognitive load factors (Leppink & Van den Heuvel, 2015; Leppink et al., 2013; Leppink et al., 2014) again in combination with objective methods like the rhythm method or eye-movement analysis to prove construct validity. The available studies (publications II and IV) show the benefits of using multiple methods to measure cognitive load and to assess cognitive processes related to single cognitive load factors. However, at this point all methods have difficulties when it comes to validly indicating changes for single cognitive load factors. Future research should specifically focus on the analysis of eye movements while learning with multimedia learning instructions because this method is highly promising concerning the identification of cognitive processes with a unique contribution to single cognitive load factors. The possibilities to differentiate between the single cognitive load factors were limited as a function of instructional design for the present studies (publications I to IV). The analysis of eye movements could only be used to differentiate between relevant information processing that was beneficial for learning and irrelevant information processing that was not beneficial for learning when the distinction was clearly outlined in the learning instruction. Future research should investigate fine grained indicators in eye movements that are less dependent on the presentation format of the learning instruction. The differentiation between different types of transitions, for example, is a suitable approach (Johnson & Mayer, 2012). Within the framework of the second study (publication II), some indicators that are based on the combination of integrative transitions and the corresponding fixation duration subsequent to a transition were already tested, but these analyses were highly explorative and further research needs controlled experimental variations on a less complex level of information processing than given in the used learning instruction. This approach could probably be used to disentangle eye movements as recorded for the mental animations group in the forth study (publication IV) and to differentiate between basic processes of information search, refreshment and generative cognitive processing that is dedicated to schema acquisition.

Finally, with regard to the models of CLT with either three (Sweller et al., 1998) or two (Choi et al., 2014; Kalyuga, 2011) cognitive load factors, the available studies (publications I to IV) support the recent model with only intrinsic and extraneous cognitive load. Whereas the seductive details effect that was used to increase extraneous cognitive load can also be explained within the three-factorial model, the effect of mental animation prompts that was used to increase germane/intrinsic cognitive load at first supports the two-factorial model and the assumption of an inherent relation between intrinsic and germane cognitive load (De Jong, 2010; Kalyuga, 2011).

However, considering only the two factors of intrinsic and extraneous cognitive load does not solve the problems concerning the measurement of cognitive load. Intrinsic cognitive load now includes task complexity based on element interactivity and generative cognitive processing dedicated to schema acquisition. The present studies (publications I to IV) show that high element interactivity does not result in a high cognitive activity that is useful for schema acquisition. Moreover, interdependencies between these two aspects of intrinsic cognitive load as well as between intrinsic and extraneous cognitive load must be considered. The available studies (publications II and IV) show such interdependency between intrinsic and extraneous cognitive load. The seductive details effect with a simultaneous decrease in intrinsic cognitive load and an increase in extraneous cognitive load shows that additional extraneous cognitive load not necessarily adds up and increases total cognitive load to the expected extent. Moreover, the results suggest that this effect was not due to an overall increase in element interactivity and task complexity but rather due to constant element interactivity for the learning objective with a decrease of engagement in generative cognitive processing. However, the present studies (publications I and III) also support the assumption of element interactivity as an important factor for cognitive load research (Chen, et al., 2016; Sweller, 2010) as low prior knowledge and low spatial ability learners were stronger affected by seductive details. Prior knowledge is assumed to decrease element interactivity (Plass et al., 2010; Sweller et al., 2011) and high prior knowledge learners can be assumed to have more available cognitive resources to handle additional extraneous cognitive load (Magner et al., 2014). The same may be true for high special ability learners as they may also have more available cognitive resources to handle extraneous cognitive load due to lower element interactivity for the mapping of textual and pictorial representations. On the other hand, the advantages of high prior knowledge learners can be explained by an enhanced information selection due to high prior knowledge (Canham & Hegarty, 2010; Haider & Frensch, 1999; Jarodzka et al., 2010) and a higher control of attention direction (Sanchez & Wiley, 2006). High spatial ability learners may have advantages concerning mental model construction due to enhanced abilities to mentally rotate, manipulate and imagine the pictorial mental models according to pictorial representations (Mayer, 2001; Münzer et al., 2009; Park et al., 2016). In fact, the interpretation is difficult and both assumptions provide plausible explanations with either a moderating effect of available cognitive capacities due to low element interactivity or a moderating effect of efficient cognitive processing due to enhanced information processing. The results of the present studies (publications I and III) suggest that in general generative cognitive processing can be affected by instructional designs without changing the element interactivity of the learning objective and that in detail the moderating effects of learner characteristics are rather based on efficient cognitive processing. However the efficient cognitive processing due to enhanced information processing could in the first place be enabled by free cognitive resources due to lower element interactivity.

The results of the fourth study (publication IV) suggest a further kind of interdependency for mental animation prompts that were used to foster generative cognitive processing. In contrast to seductive details, the element interactivity was raised by mental animation prompts and the assumption is close that especially learners who were able to handle the increased element interactivity profited from the mental animation prompts. For learners who could not handle the increased element interactivity, the increase in intrinsic cognitive load may have caused harmful effects on learning that are comparable to an increase in extraneous cognitive load. Concerning the effects of instructional designs to foster generative cognitive processing future research should investigate moderating effects of learner characteristics and focus on the interdependency between intrinsic and extraneous cognitive load as a function of the learners' prior knowledge and element interactivity (Kalyuga et al., 2003).

Given the interdependencies between intrinsic and extraneous cognitive load that are moderated by learner characteristics, it is nevertheless necessary to develop methods to disentangle cognitive processes that are beneficial for learning and those that are not and to measure these two factors of cognitive load separately and in relation to the corresponding cognitive processes. Element interactivity that determines task complexity is affected by prior knowledge and generative processing must be assumed as well to increase or decrease as a function of task complexity and learner characteristics. Thereby, the intrinsic cognitive load should be considered to result from cognitive processing that includes the necessary cognitive load to handle the task complexity and the cognitive load that indeed results in generative cognitive processing and schema acquisition. The three-factorial model (Sweller et al., 1998) considered intrinsic cognitive load as task complexity that was in general nor good or bad but given, extraneous cognitive load due to the instructional design that was bad and germane cognitive load due to schema acquisition that was good (Kirschner et al., 2011). The two-factorial model (Choi et al., 2014; Kalyuga, 2011) must consider that schema acquisition is not a simple function of task complexity but an interaction with learner characteristics and therefore intrinsic cognitive load must be assumed not only to be given but to be good or bad as well. This interaction between task complexity and learner characteristics was already part of the CLT model of Paas and Van Merrienboer (1994) and is again of great importance for the recent two-factorial model of CLT. Thereby, the task-learner-interaction is not only important for the theoretical conceptualization of the revised intrinsic cognitive load factor but also for practical development of methods for cognitive load measurement. Task complexity should further be assessed as it is important to know the initial position concerning the task-learner-interaction. Cognitive processes should in the following be assessed with regard to the benefits for schema acquisition and methods should distinguish between beneficial and unbeneficial cognitive processes with regard to the learning objective that are either based on task complexity (intrinsic) or on presentation format (extraneous).

However, this suggestion to identify the beneficial parts of cognitive load is based on the results of the present studies (publications I to IV) and the promising possibilities to measure different aspects of cognitive load in relation to the corresponding cognitive processes. With regard to CTML (Mayer, 2001, 2005), at least the amount of cognitive load for selecting relevant text and pictures as well as for organizing verbal and pictorial representations should be measureable and distinguishable from processes of information search or cognitive activity to keep up the selected information in working memory by the analysis of eye movements. The final question to be discussed is whether CLT needs such kind of detailed differentiating measurement to facilitate research on learning and instruction. In general, a simple differentiation between intrinsic cognitive load due to task complexity that results from element interactivity and extraneous cognitive load due to the presentation format of the learning instruction may be sufficient to explain learning success as a function of cognitive load. For research that is aimed at reducing extraneous cognitive load by an improvement of the presentation format, the measurement of cognitive processes to handle the presentation format is essential and the measurement of cognitive processes to deal with task complexity provides information about possible interdependencies between intrinsic and extraneous cognitive load.

For research that is aimed at increasing intrinsic cognitive load by an increase of task complexity to foster generative cognitive processing, the measurement of cognitive processes to handle the task complexity is essential but prior knowledge should by all means be considered as moderator as an increase in task complexity can also cause a decrease in generative processing. The measurement of high cognitive load to handle task difficulty can result in an increase as well as in a decrease in learning success that will be moderated by learners' prior knowledge. In this case and without advanced differentiation, cognitive load will rather be interpreted according to learning success than be measured by assessing the cognitive processes to deal with task complexity. In contrast, for research that is aimed to foster generative cognitive processing by a decrease of task complexity, a decrease in intrinsic cognitive load should only be present for high prior knowledge learners and the measurement of cognitive processes to handle the task complexity should be sufficient as long as prior knowledge is considered as moderator for the analysis. In sum, a detailed and differentiating measurement of cognitive load is necessary when an increase in task complexity due to element interactivity is expected to increase generative cognitive processing as a function of individual learner characteristics such as the element interactivity effect (Sweller, 2010) or the worked example effect (Moreno, 2006). Moreover, a detailed and differentiating measurement is needed when considering a more flexible approach of CLT with a differentiation between intrinsic and extraneous cognitive load due to the learning objective as it is necessary for complex learning situation and problem solving (Kalyuga, & Singh, 2015; Schnotz & Kürschner, 2007). The results of the present studies (publications I to IV) suggest that a differentiation of at least these two cognitive load factors can best be achieved by a combined use of objective and subjective measurement methods that should preferably include eye-movement analysis and subjective ratings of task difficulty. Although further research is needed to validate this kind of combined cognitive load measurement methods, the approach is highly promising concerning a detailed analysis of cognitive processes and corresponding cognitive load with regard to a flexible two-factorial model of CLT (Choi et al., 2014; Kalyuga & Singh, 2015).

7. References

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Appendix

Publication I: **Do learner characteristics moderate the seductive-details-effect? A cognitive-load-study using eye-tracking**

Publication II: **Measurement of Cognitive Load in Multimedia Learning: A Comparison of Different Objective Measures**

Publication III: **Learner Characteristics and Information Processing in Multimedia Learning: A Moderated Mediation of the Seductive Details Effect**

Publication IV: **Differentiating Different Types of Cognitive Load: A Comparison of Different Measures**