Attention Cueing in an Instructional Animation

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Attention Cueing in an Instructional Animation

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Chapter

1

General introduction

In modern educational environments, dynamic visual representations such as animations are increasingly used for presenting change-related information. Due to the increased accessibility of technologies and its ongoing developments capable of rapidly producing powerful visualizations, animations have quickly become one of the most popular instructional materials in learning design (Chandler, 2009). Instructional animations help visualizing processes that are dynamic in nature by explicitly showing the changes in the depicted system or procedure. They therefore provide a realistic and vivid representation of the information to be learned. Because of its capacity to convey concepts such as motion, acceleration, and trajectory in a single visual display it has been claimed that animations are the most convenient instructional resource for demonstrating sequential events in procedural tasks, visualizing abstract or invisible concepts, illustrating tasks that are difficult to verbalize, or simulating complex causal system behaviors (Park & Hopkins, 1993; Wetzel, Radtke, & Stern, 1994). As the changes in a dynamic system can be perceived by simply looking at an animation, learners are not required to mentally infer the dynamic information from static visualizations (i.e., mental animation, Hegarty, 1992), which should help them in developing a better understanding and hence a more accurate mental representation of the presented information.

Despite some evidence that animations can produce improved learning under some specific conditions (Höffler & Leutner, 2007), a considerable amount of evidence consistently indicates that animation-based instruction is frequently no more or even less effective than learning with static visualizations that require far less time and effort to design (Mayer, Hegarty, Mayer, & Campbell, 2005; Tversky, Morrison, & Bétrancourt, 2002). Further, evidence is accumulating that animations can pose their own distinctive challenges to learners (Boucheix & Guignard, 2005), particularly when they depict complex dynamic content that is unfamiliar to the target population (Lowe, 2004).

Processing animations

Although a complete understanding of the crucial factors involved in the effectiveness of animations is still lacking, it seems that the simultaneous depiction of multiple changes and the continuous flow of information play an important role in effective animation design (Ainsworth & VanLabeke, 2004; Ayres & Paas, 2007; Lowe, 1999). Cognitive load theory (Sweller, 1999), for example, argues that due to the restrictions of working memory, both regarding duration and capacity (Cowan, 2001; Miller, 1956), learning from animations may be hindered because learners are often unable to hold information active in working memory for longer periods of time and can only process a limited number of elements at any moment in time. Accordingly, several researchers have argued that the high information load, combined with the temporally distributed nature of the presentation may place (too) high cognitive load on the learner's cognitive resources (Ayres & Paas, 2007) and results in suboptimal elaboration processes as too much happens too fast (Lowe, 2003; Tversky, Heiser, Lozano, MacKenzie, & Morrison, 2008; Tversky et al., 2002).

Especially, learners inexperienced in a domain may have difficulties or experience high processing demands when they try to extract the most relevant information from animations that portray many elements and exhibit complex temporal patterns. The individual elements comprising an animation typically show considerable variation in terms of their perceptibility as well as how important they are for building a coherent mental representation (Lowe, 2005). Trying to understand animations, therefore, requires learners to effectively divide their visual attention over all elements in the visual display, which may move from one location to the other and might change with respect to different perceptual characteristics (e.g., color, form, orientation). Moreover, human visual attention is almost automatically attracted by dynamic and salient information such as movements, sudden onsets, and bright colors (Franconeri & Simons, 2003; Hillstrom & Chai, 2006; Treisman & Gormican, 1988). Therefore, animations may distract learners' attention from crucial information or cause learners to favor the processing of the most prominent aspects of animations, irrespective of whether or not the elements are relevant for understanding the content (Lowe, 1999, 2003). The process of locating task-relevant information may thus require a large amount of ineffective working memory resources, because highly salient but irrelevant information needs to be suppressed to avoid unnecessary visual searches or attentional resources need to be constantly redirected to focus on relevant elements (Ayres & Paas, 2007).

Further challenges to the extraction of relevant information can occur due to the importance of elements in different temporal locations. Elements may have high relevance at specific stages of an animation or the components and relationships that are fundamental to understanding a dynamic system's causal structure may be separated over the course of an animation. If elements participate in various events during an animation and several currently visible elements need to be integrated with previously presented information, important information might be missed or only partially processed because the information is only briefly available and there is no opportunity to re-inspect it.

Directing learners' visual attention

In order to increase the possibility that learners extract the task-relevant information from an animation and use this information to construct a coherent mental representation of the depicted content, it has been proposed to direct the learners' attention to the right locations in the visual display and at precisely the right times (Bétrancourt, 2005; Schnotz & Lowe, 2008). A suggested fruitful approach for improving learning from animations by guiding attention to its most essential aspects is *cueing*, which some researchers refer to as *signaling* (Mautone & Mayer, 2001; Meyer, 1975). Cues are non-content devices such as arrows and colors that are added to the visual display to reduce the search space a learner must explore and so increase the likelihood that task-relevant aspects come into the focus of attention. They do not provide new information or change the content of the instructional materials (Lorch, 1989). Rather, cues are intended to help learners in selecting relevant information, and organizing and integrating the information into a coherent representation (Mayer, 2001). By adding a visual cue to a complex animation the visual search associated with locating relevant aspects should be reduced, thereby reducing ineffective cognitive load (i.e., extraneous cognitive load, Paas, Renkl, & Sweller, 2003) and allowing more cognitive resources to be allocated to learning.

Although the effect of cueing is essentially perceptual, prior research with static representations indicates that visual cues have clear implications for conceptual understanding. A considerable amount of research indicates that cueing may improve the recall of texts, its organization in memory, and may lead to a better understanding of text content (e.g., Loman & Mayer, 1983; Lorch, 1989; Lorch & Lorch, 1996; Lorch, Lorch, & Inman, 1993). Similarly, several studies have shown that cues may improve learning from text and pictures (e.g., Jeung, Chandler, & Sweller, 1997; Kalyuga, Chandler, & Sweller, 1999) or pictures alone (Grant & Spivey, 2003) by reducing visual search for relevant or related elements and hence the extraneous cognitive load associated with it. For example, Kalyuga et al. (1999) demonstrated that using color-coding to make the link between textual and pictorial information more clear, improved learners' understanding of the presented information. Moreover, some evidence has been found that cues can reduce the amount of experienced cognitive load (Jamet, Gavota, & Quarieau, 2008; Kalyuga et al., 1999) whereas other studies have found better learning without reduced cognitive load (Tabbers, Martens, & van Merriënboer, 2004), which suggests that cues can effectively increase working memory resources essential for learning. So, guiding learner's attention to relevant aspects in static representations by cueing them increases the possibility that learners extract the right information and allows them to process the information more deeply and hence improve their understanding.

Outline of the dissertation

At present, there is hardly any evidence that animations have clear advantages over static representations on learning of change-related information (for a review see Tversky et al., 2002). The generally positive findings about cueing on learning from static depictions suggest that focusing learners' attention on relevant parts of an animation by cueing them might be an effective way to improve learning from animations. The aim of the studies described in this dissertation was therefore to investigate whether and under which conditions cueing may improve learning from animations. Based on cognitive load theory, the main hypothesis was that cueing improves learning from animations by reducing visual search and its associated extraneous or ineffective cognitive load, so that learners have more working memory resources available for learning-related activities.

The studies presented in Chapters 2 through 7 can roughly be divided into three parts. Chapters 2, 3, and 4 focus on the effects of cueing on understanding and the construction of a mental representation purely from a dynamic system via animation without any accompanying description. By not providing additional written or spoken descriptions, we can be sure that learning outcomes only reflect learners' understanding of the dynamic visualization itself. The studies in Chapters 5 and 6 tested whether explanations, either provided to learners or generated by learners themselves through self-explaining, improve the effectiveness of cueing in an animation. In Chapter 7, the empirical studies presented in this dissertation are placed in a broader perspective by comparing the effectiveness of cueing in animations to the effectiveness of cueing in static representations. Finally, the conclusions of the studies described in this dissertation are presented in Chapter 8 and their implications for the design of animations as well as directions for future research are discussed.

The studies

In what is often considered the first study of cueing in animations, Mautone and Mayer (2001) arrived at the conclusion that visual cues in an animation did not improve retention and transfer performance compared to an animation without visual cues. One of the explanations they proposed for this finding was that the animation contained few simultaneously occurring events and therefore did not require the guidance of cues. However, in more complex animations cues may still be required for focusing learners' attention on relevant information in order to distinguish this information from irrelevant information. Therefore, the study in **Chapter 2** investigated whether cueing in a complex animation with many simultaneously presented elements reduces the extraneous cognitive load associated with searching for relevant elements and improves learners' understanding of the presented information. The functioning of the heart (i.e., cardiovascular system) was used for the animation in this study as well as for the empirical studies described in Chapters 3 through 6, as it comprises a set of multiple interacting subsystems that exhibit individual temporal and spatial patterns that interact and need to be organized into a coherent representation to understand the entire system. The effect of cueing on processing the animation was investigated by comparing an uncued version with a version in which one of the five subsystems of the cardiovascular system was cued by 'highlighting'. A single subsystem was chosen to be cued in order to ensure that any observed cueing-effects could be solely ascribed to cueing rather than sequencing effects as a result of cueing multiple subsystems consecutively. The influence of cueing on comprehension and transfer performance was tested by individually examining questions about the cued subsystem and questions about the uncued subsystems of the animation. Learners reported their invested mental effort as a subjective measure of cognitive load (Paas, 1992).

The study in **Chapter 3** experimentally tested whether the number of interacting elements that should be processed simultaneously per unit of time influences the instructional effectiveness of cueing. This study was a replication of the study in Chapter 2 but the factor presentation speed is also introduced. That is, the cued and uncued animations were presented at a much faster or slower presentation speed. The idea was that by presenting the animation at a faster presentation speed, the cognitive load that is imposed on learners is increased due to a higher number of elements that should be attended to and processed per unit of time. Therefore, cueing should be very helpful in assisting learners to focus their attention on the right parts of the animation at the right time and consequently the construction of an accurate mental representation of the system's dynamics. On the other hand, if the number of presented elements per time unit, and hence cognitive load, is low by presenting the animation at a low presentation speed, a cue may be unnecessary. Learning from a cued animation should therefore improve comprehension and transfer performance with a high but not with a low presentation speed. So, this study directly tested the assumption that cueing may only be effective at enhancing learning if the animation consists of many simultaneous changes and produces high cognitive load on learners' working memory.

In **Chapter 4**, the perceptual and cognitive processes involved in learning the animation, and not just the outcomes of these processes, were examined in order to uncover detailed information on how cues influence this learning process. This may provide important insights into whether learners actually allocate their attention to the cued parts, to what extent cues have an influence on the amount of visual search, and the role cues play in building a mental representation from animations. Eye tracking was used to register the learners' eye movements in order to assess overt visual attention allocation to cued and uncued parts and to investigate whether or not cueing leads to reduced visual search. In addition, the eye movement records were used as a cue for verbal reports in order to assess the cognitive processes that occurred during learning (i.e., cued retrospective reporting, Van Gog, Paas, & van Merriënboer, & Witte, 2005). Furthermore, learning outcomes were measured with comprehension and transfer tests. In addition, learners subjectively reported their invested mental effort on a rating scale, which was used to determine whether or not cueing reduces cognitive load during the learning and testing phase. In contrast to the studies described in Chapter 2 and 3, this study also investigates the effects of cueing all subsystems sequentially in addition to comparing cueing of a single subsystem to an uncued animation. Because the construction of a coherent mental representation depends to a large extent on the understanding of the functioning of all subsystems and their interactions, cueing all parts of the cardiovascular system should improve learners' understanding compared to cueing a single subsystem or not cueing the animation. So, another aim of this study was to investigate this hypothesis.

The studies reported in Chapters 2, 3, and 4 focus on helping learners to gain a better understanding of an animation by reducing the working memory demands associated with processing irrelevant, or extraneous, information by using visual cues. However, research by Kriz and Hegarty (2007; also see Chapter 4) has indicated that attention-directing cues alone do not necessarily affect cognitive processing, but mostly seem to play a role in what locations in animations receive attention. Furthermore, there is a lack of research on the factors that might influence learners' cognitive processing in building an integrated and coherent mental representation from animations. Therefore, the study in **Chapter 5** investigated whether stimulating learners to actively process the information during the animation by prompting them to explain to themselves why particular movements and changes occur, and what this information implies (i.e., self-explaining, Chi, Bassok, Lewis, Reimann, & Glaser, 1989) may improve learning from cued and uncued animations. As learners were required to learn the complete functioning of the cardiovascular system, all subsystems were consecutively cued. It was expected that self-explaining would only increase learning performance compared to studying the animation without self-explaining, if the learners' attention is focused on the relevant parts of the animation so that they do not have to determine which parts are relevant and need to be attended to and which parts are irrelevant and need to be ignored. Learning outcomes were measured with retention, inference and transfer tests, whereas invested mental effort was measured with a cognitive load rating scale in order to look at how cueing and self-explaining influence cognitive load during the learning and testing phase. Furthermore, the learners' think-aloud self-explanation protocols, which provide a valuable information source of the learners' ongoing thought processes while viewing the animation, were analyzed to determine the quality of the self-explanations.

In line with Chapter 5, **Chapter 6** also examines the learners' internal processing activities in relation to studying a cued and an uncued animation. Although this study replicated the methodology and measures of the study described in Chapter 5, there is one crucial difference. In Chapter 5, it was investigated whether self-explaining with cued and uncued animations was more effective in terms of learning than studying an animation without self-explaining. The study reported in Chapter 6 attempted to shed light on whether constructing an accurate representation from an animation of the cardiovascular system was most effective if the explanations are generated by the learners through self-explaining or if explanations are provided to learners as a narration accompanying the animation. In addition, it was studied whether or not the explanations need to be supported by visual cues in the animation. Due to the incompleteness of and the inaccuracies that may arise during self-explaining, providing explanations to learners should enhance their understanding of the animation compared to self-explaining with an animation. The goal of this study was to test this hypothesis. In addition, it was expected that learning from an animation with explanations would lead to better understanding of the animation if it was studied with instead of without cues. Furthermore, the learners' think-aloud self-explanation protocols were analyzed to determine the completeness and the quality of the self-explanations.

Chapter 7 compares and discusses the effectiveness of cueing in static representations (i.e., text and/or pictures) and dynamic representations (i.e., animations) on perceptual and cognitive processing. It provides a broad framework of the different purposes and functions that cueing may have in instructional materials. In light of this framework, the results of the studies presented in Chapter 2, 3, and 4 as well as several other studies in the field that have examined cueing in animations are discussed in this wider context. In addition, factors that influence the effectiveness of cueing in animations are identified and recommendations for future research and practical implications are provided.

Finally, in **Chapter 8**, a summary and general discussion of the main findings reported in the studies of this dissertation is provided and directions for future research are described.

Chapter

2

Attention cueing as a means to enhance learning from an animation[1]

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Abstract

The question how animations should be designed so that learning is optimized, is still under discussion. Animations are often cognitively very demanding, resulting in decreased learning outcomes. In this study, we tried to prevent cognitive overload and foster learning by focusing the learners' attention to one element (i.e. process) of an animation using a cueing technique. Psychology students viewed an animation of the cardiovascular system and were subsequently given a comprehension test and a transfer test. One group studied the animation without a visual cue, while for another group a visual cue was added to the animation. Results indicated that cueing not only enhanced comprehension and transfer performance for cued information, but also for uncued information. It is concluded that cueing can be used as a technique to improve learning from an animation. Results are interpreted in terms of cognitive load theory (CLT).

Introduction

Dynamic visualizations, such as animations, showing complex dynamic processes, may be especially supportive in the construction of elaborated schemata. Both educational practitioners and instructional designers often assume that animations have important advantages over static graphics, especially in providing motion and trajectory information (Mayer & Moreno, 2002; Rieber, 1990), making them a popular instructional tool. However, evidence is accumulating that animations are not instructionally superior to static graphics (Mayer, Hegarty, Mayer, & Campbell, 2005) and most reviews have concluded that animations are at best no more and sometimes even less effective than the equivalent static graphics (Bétrancourt & Tversky, 2000; Hegarty, Kriz, & Cate, 2003; Tversky, Morrison, & Bétrancourt, 2002). Despite the widespread use of animations in educational practice (Lowe, 2001), little is known about how such learning materials are cognitively processed (Lowe, 1999, 2004) and how they should be adapted to make learning more effective. Therefore, systematically studying the cognitive processes involved in learning from animations is of major importance.

Cognitive Load Theory (CLT; Sweller, 1988; Sweller, van Merriënboer, & Paas, 1998) provides a theoretical framework that explains why learning from animations often fails. According to this theory, three sources of cognitive load can be imposed on learners when learning from animations. Intrinsic cognitive load is imposed by the information elements in the learning material and their interactions. Extraneous cognitive load is imposed on learners when mental activities, which are not directly related to learning (e.g. high visual search), are required to understand the material and is often the result of poorly designed instruction. Changing the instructional format can reduce extraneous load and promote learning. Germane cognitive load is imposed when information is presented in a way that learning is enhanced. For example, when mental activities such as elaboration and organization of information result in the construction and automation of schemata. According to CLT, the combination of high intrinsic load (i.e. many interacting information elements) and high extraneous load (i.e. transience and high visual search) may account for suboptimal learning from animations.

The essential characteristic that distinguishes animations from static ways of presenting information is their higher complexity, as they incorporate motion and temporal aspects. Because information is transient, learners have to process current information and remember previous information simultaneously. If both current information and previous information have to be considered simultaneously to be understood, comprehension may fail because information presented during earlier phases of the animation may be forgotten or has become less clear. So, learning from an animation instead of a static picture may impose a higher cognitive load and thus may require other strategies, both cognitive and perceptual (Lowe, 1999).

Furthermore, a prerequisite for constructing coherent schemata of the subject matter domain displayed in an animation is that all relevant elements in the animation are attended to and extracted appropriately. However, animations are often visually too complex to be accurately understood, for example, because attention should be directed to several simultaneously occurring events (Hegarty et al., 2003; Schnotz, Böckheler, & Grzondziel, 1999; Tversky et al., 2002). In a study by Lowe (1999) participants were presented with an animated training of how weather maps change in order to help them build a mental model of weather maps. They subsequently had to predict how the markings on a static weather map would change on the next day. Results revealed a perceptual dominance effect, implying that perceptually salient features of the animation drew learners' attention away from the thematically more relevant, but perceptually less salient features. This suggests that learning is enhanced when salient features correspond to thematically relevant aspects. Otherwise, the search for and extraction of relevant elements becomes a difficult additional task, which may impose high levels of extraneous load on learners relatively inexperienced in a domain who do not possess the necessary schemata to help them distinguish relevant from irrelevant information. In this case, an animation involving several simultaneously occurring events may never be effective for learning.

However, from a cognitive load perspective, animations may be less demanding and may become more effective when they are designed in a way that extraneous load is minimized. A possible way to reduce extraneous load, without reducing the informational richness of animations (e.g., motion and timing), is by focusing the learners' attention on relevant aspects in an animation by cueing them, which Bétrancourt (2005) refers to as the attention-guiding principle. By adding a visual cue to a complex animation visual search should be reduced, thereby reducing extraneous load and allowing more cognitive resources to be allocated to learning.

Cueing

Cueing was originally defined as 'the addition of a non-content aspect of prose, which gives emphasis to certain aspects of the semantic content or points out aspects of the structure of the content' (Meyer, 1975, p.77). When applied to animations, cueing can be defined as the addition of non-content information that captures attention to those aspects that are important in an animation (e.g. coloring, arrows). So, cues are intended to guide the learners' cognitive processing but are not intended to provide new information (Mautone & Mayer, 2001).

Although there is a large body of research showing the added value of cueing in texts (Loman & Mayer, 1983; Lorch, 1989; Lorch & Lorch, 1996; Lorch, Lorch, & Inman, 1993), only a few studies have addressed the instructional value of cueing in other learning resources. Several studies, in which two separate sources of information, such as on-screen or narrated text and pictorial information have to be integrated, clearly demonstrate that cueing can be very effectively used to reduce visual search in a multimedia explanation (Jeung, Chandler, & Sweller, 1997; Kalyuga, Chandler, & Sweller, 1999; Tabbers, Martens, & van Merriënboer, 2004). Kalyuga et al. (1999), for example, found that the use of color coding as a visual cue to establish a link between textual and pictorial information, resulted in much better learning outcomes. However, mixed results have been obtained with respect to the effect of cueing on cognitive load, indicating that sometimes cognitive load is slightly lowered by adding visual cues (Kalyuga et al., 1999), while in other situations cueing has no significant effect on reported mental effort (Tabbers et al., 2004). However, this does not necessarily imply that cueing was not effective in reducing extraneous load. In general, instructions should be designed to decrease extraneous load and optimize germane load. Although the overall amount of cognitive load may not differ, the relative contribution of extraneous and germane load can vary with different instructions.

The only study that directly addressed cueing in an animation showed that the incorporation of visual cues to an animation did not enhance learning (Mautone & Mayer, 2001). In this study, a narrated animation was studied in which the narration and the animation could either be cued or uncued. No significant effects of visual cueing were found for the animation on retention and transfer. To explain these results, Mautone and Mayer argued that the animation was too simple and contained few distracting elements. In other words, the animation represented no simultaneously occurring processes, so cues were unnecessary in directing attention and reducing extraneous load.

Cueing has only been investigated in a multimedia context to reduce the search for appropriate referents in a text and accompanying picture. Yet, little is known about how cueing affects learning from visual-only instructions in animations. In addition, cueing in animations has only been studied in a low visual search situation. As cueing is expected to be most effective in high visual search situations, valid conclusions about cueing in animations can only be made when investigated under high visual search conditions.

The aim of the present study was to determine whether cueing a complex animation of the cardiovascular system would result in better learning outcomes (i.e. comprehension and transfer) than presenting the same animation without a visual cue. It was hypothesized that the animation would only enhance learning for learners with moderate prior knowledge when irrelevant visual search was reduced by guiding attention by adding a visual cue. To avoid ordering and segmentation effects as a result of cueing different processes serially, only one process was visually cued. Based on CLT it could be predicted that adding a visual cue to a visually complex animation will accomplish a decrease in extraneous load and hence makes the instructional animation more effective in terms of learning (i.e. germane load). According to CLT, experiencing less extraneous load during learning frees up working memory resources (Sweller, 1999). Therefore, in line with Kalyuga et al. (1999), a small effect of cueing on either mental effort scores or test performance is predicted. That is, there may be equal test performance but less mental effort involved in studying the animation with an added visual cue than when no visual cue is present in the animation. Alternatively, both conditions may experience the same amount of mental effort but yield better performance when a visual cue is added to the animation. To address not only the effectiveness of instructions by looking at test results but also the efficiency of the instructions, a subjective measure of mental effort was also administered after the comprehension and transfer test to assess whether the same performance took the same amount of mental effort. Furthermore, by cueing one complete process, attention is directed to a meaningful unit of information, that is, a functional important part of the cardiovascular system. Therefore, it is reasonable to assume that cueing has a large effect on the performance of the questions about the cued process. To investigate this possibility, a more specific prediction was that cueing one process would result in better comprehension and transfer outcomes on the questions concerning that process.

Method

Participants

The participants were 40 undergraduate psychology students (10 males and 30 females) from the Erasmus University Rotterdam. Age ranged between 19 and 33 years. All were native Dutch speakers and received partial course credit or a small monetary reward for their participation. Participants had normal or corrected to normal vision, were unaware as to the exact purpose of the study, and gave informed consent.

Design

The experiment conformed to a 2 Cueing (Yes vs. No) × 2 Question-type (Valves vs. Other processes) mixed factorial design. The factor Question-type was manipulated within participants and the factor Cueing was manipulated between participants resulting in two conditions: the No-Cueing (NC) condition and the Cued-Animation (CA) condition. Participants were randomly assigned to the experimental conditions, with 20 participants in the NC-condition and 20 participants in the CA-condition. In the NC-condition, participants were presented an animation of the cardiovascular system without any cues. Participants in the CA-condition viewed the same animation, but with the process of how the valves of the heart work cued. To determine whether both groups differed in their amount of prior knowledge of the cardiovascular system, we investigated their prior knowledge by adding up the scores on a checklist (see Appendix A) and using the students' self-rating concerning their knowledge about the cardiovascular system. Analysis of this prior knowledge score indicated no significant differences between the cued animation condition ($M = 6.9$, $SD = 3.19$) and the uncued animation condition ($M = 5.4$, $SD = 3.00$), $t(38) = 1.686$, $p>0.05$.

Materials

The materials consisted of an animation, a participant questionnaire, a cognitive load rating scale, a comprehension test, and a transfer test. All materials were combined into one computer application and this program was presented on a 17" LCD color computer screen.

An animation of the cardiovascular system (Figure 1) was created for the purpose of this study. To assure that the information presented in the animation was a realistic depiction of the cardiovascular system, the animation was developed in collaboration with two physicians. The animation consisted of five basic processes of the cardiovascular system that are distinguished in medical education: the circulatory system, the electrical system, the pulmonary circulation, the systemic circulation, and the valves system. All five processes have their own role and function at their own pace. However, all processes interact with each other and hence each process is contingent on the proper functioning of the other processes. In short, the animation shows how the heart expands as it fills with blood and shrinks as blood is pumped out of the heart, how the lungs expand when oxygen flows into the lungs to the alveoli and shrink when waste products flow from the alveoli out of the lungs, how and when the valves of the heart open and close, how and when the electrical system is activated and how this activation spreads along the heart muscle causing it to contract, the direction and pathway of the blood flow, where and when oxygen is taken up in the blood and waste products are given off, where and when oxygen is given off to muscles in the body and waste products are taken up, the timing between all these simultaneously occurring processes.

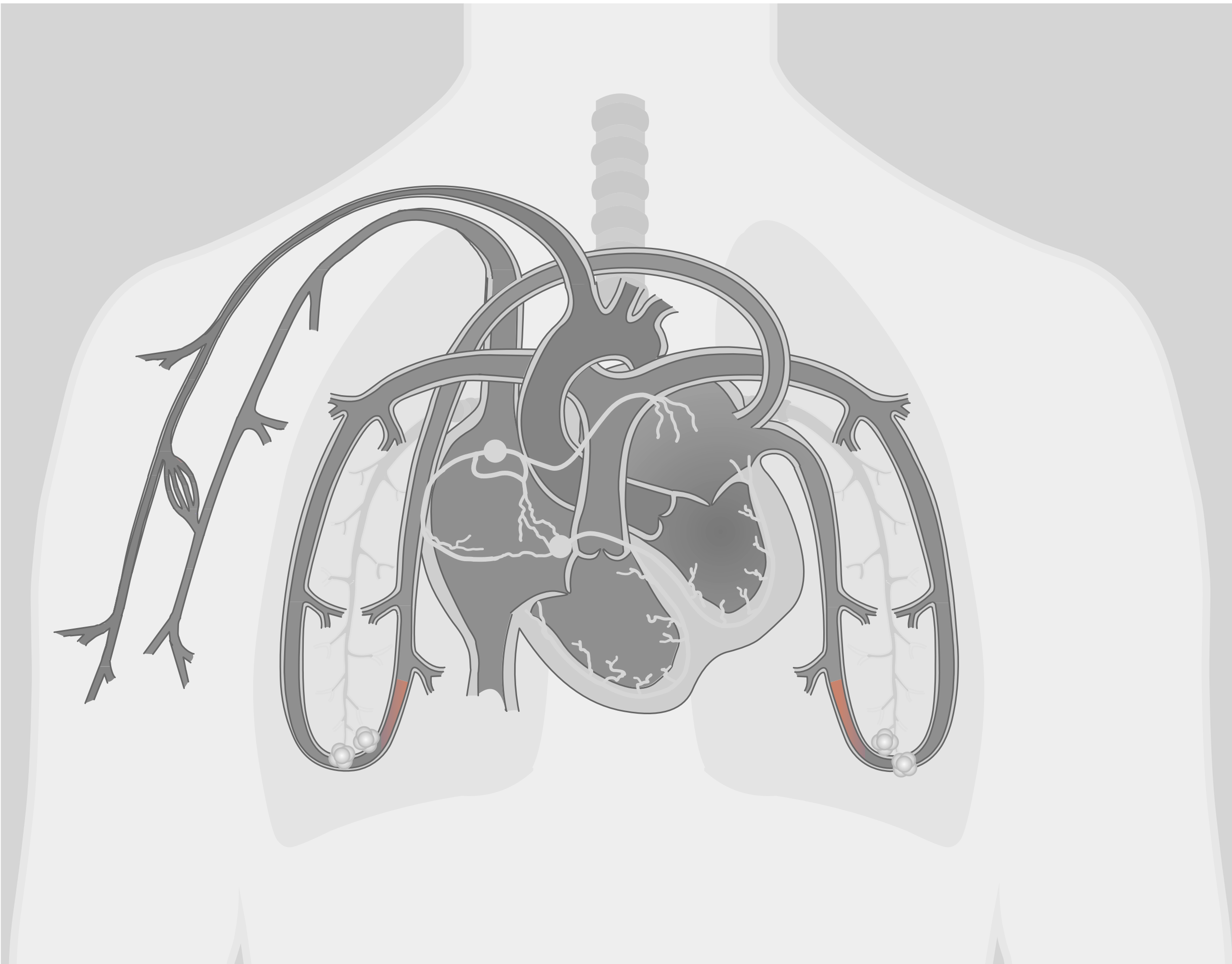


Figure 1 *Screenshot of the animation of the cardiovascular system*

Our main goal was to enhance knowledge of the dynamics of the cardiovascular system rather than learning the specific names and locations for each part of the cardiovascular system. Therefore, we did not include information about terminology or anatomy of the cardiovascular system. Moreover, participants had taken at least some basic biology courses in high school that included the cardiovascular system and its basic components. Prior testing indicated that the names and locations of these components, but not their functions, were well known and that a total of six cardiac cycles was the average number of cycles to reach quite a good understanding of the information presented in the animation. Therefore, a total of six cardiac cycles was shown in the animation, each lasting for 10 seconds. The total duration of the animation was 60 seconds and the animation did not contain any textual information. So, participants had to rely only on the visual information to extract meaning from the animation.

Two versions of the same animation of the cardiovascular system were used in this study. One version showed the workings of the cardiovascular system without a visual cue and one version showed the workings of the cardiovascular system but now the valves of the heart were visually cued. A complete functionally important process was cued instead of specific subcomponents of such a process, because a study by Lowe (1999) suggests that cueing small elements diverges attention away from the more relevant elements, which imposes a high extraneous load and hinders the construction of elaborated schemata. The valves system was chosen as the process to be cued, because this system is an important functional part of the cardiovascular system, but is not very salient (Lowe, 1999). To ensure the visual cue attracted attention appropriately and was not conceived of as part of the animation, the visual cue appeared 10 seconds after the start of the animation, instead of right from the beginning and was visible until the end of the animation. Thus, the valves were cued after one cardiac cycle was completed and remained highlighted during five cardiac cycles. Cueing was done by slightly darkening all elements in the animation except the valves of the heart, which can be thought of as a spotlight-effect (Figure 2), that was defined in this study as a situation in which one process is highlighted and, therefore, stands out against all other processes in the animation. It is important to note, that all uncued elements could still be accurately perceived. So, with the exception of the cued process, both versions were identical. Both versions were created using Macromedia Flash 7.0 (Macromedia, 2004). Furthermore, to ensure that any effects of cueing could not be confounded with interactivity, which introduces an additional way, next to cueing, to manage the perceptual complexity by controlling the pace and direction of the animation (Bétrancourt, 2005), it was impossible to stop or to replay the animation, which is comparable to prior research (Mautone & Mayer, 2001; Mayer, Heiser, & Lonn, 2001).

The participant questionnaire, based on Mayer and Moreno (1998), asked participants to indicate their gender, age, years of university education, and knowledge of the cardiovascular system. The knowledge of the cardiovascular system was assessed using a 1-item self-rating and a 4-item checklist (see Appendix A). On the 1-item self-rating question participants were asked to indicate their knowledge of the heart and the blood flow on a 5-point scale ranging from very little (1) to very much (5). The 4-item checklist consisted of items concerning knowledge about the cardiovascular system. For example, participants were asked whether they had followed any biology classes during their secondary education or whether they knew someone in their inner circle with a heart condition. All questions regarding prior knowledge were added up to get a score, indicating overall experience of the cardiovascular system, ranging from no experience (0), to high experience (14).

The mental effort measure used in this study was a 9-point rating scale, ranging from very, very easy (1), to very, very difficult (9), and was developed by Paas (1992).

Subjective self-ratings of invested mental effort were chosen, because they are non-intrusive and they give a reliable and valid indication of experienced complexity of the task at hand

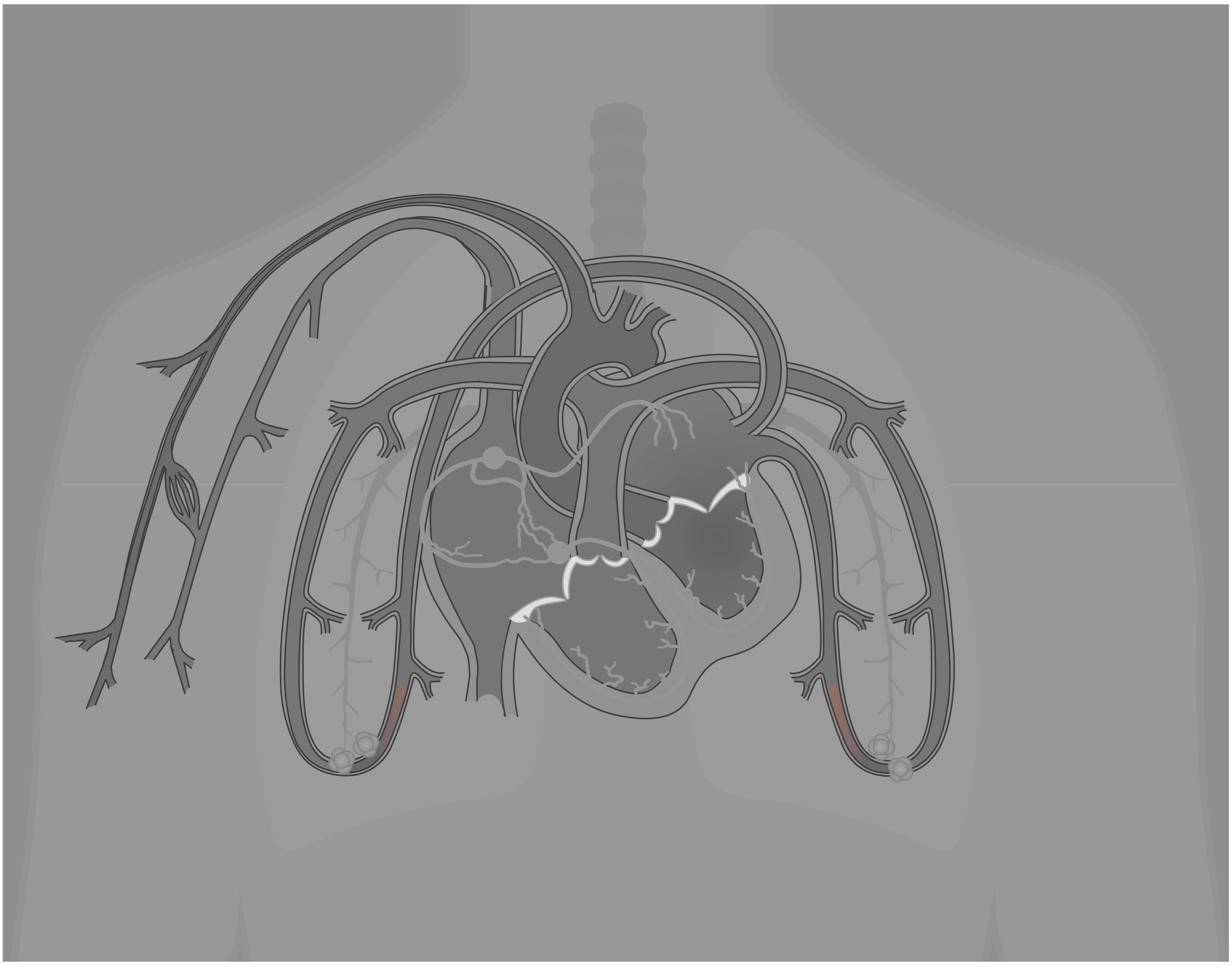


Figure 2 *Screenshot of the animation of the cardiovascular system with the valves of the heart visually cued*

(Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Paas & van Merriënboer, 1993, 1994; Paas, van Merriënboer, & Adam, 1994).

The comprehension test consisted of 38 multiple-choice questions, asking participants to indicate the correct answer out of four options. The multiple-choice questions covered all five processes and elements included in the animation. The multiple choice questions could be divided into 10 questions directly related to the functioning of the valves of the heart and 28 questions about the other four processes of the cardiovascular system (e.g. the electrical system). To assure that the comprehension test included questions about structural, procedural, and temporal aspects of the processes of the cardiovascular system, we used these three categories as an aid to develop the comprehension questions. Whenever possible, questions were formulated visually and hence made minimal use of terminology. Appendix B shows examples of comprehension questions for each category and process. All comprehension questions were evaluated by a physician.

The transfer test consisted of 10 open-ended questions and covered all processes and elements included in the animation. Examples of transfer questions are: 'Explain why the heart contracts faster when someone holds his breath?', 'Explain what causes the valves of the heart to open and close', 'Which part of the blood flow contains hardly any waste products? Explain your answer', 'The workings of the electrical system can be divided into two steps. Explain why this is'. These questions can only be answered by making inferences from the information presented in the animation and, therefore, provides a good measure of the quality of the schema that is constructed (Mayer, 2001). Out of all 10 transfer questions, two explicitly asked to make inferences about the functioning of the valves of the heart. All transfer questions were evaluated by a physician.

Procedure

Participants were tested in groups up to four people. They were seated at a computer screen and worked through the entire application at their own pace. First of all each participant was asked to fill out the participant questionnaire. Then they read instructions that stated that the animation should be attended to carefully, and they were explicitly encouraged to comprehend how the cardiovascular system works. Furthermore, it was announced that they would be tested afterwards on the cardiovascular system. Depending on the condition, they viewed either the cued animation or the uncued animation. After viewing the animation, participants were given a mental effort rating scale on which they could rate their invested mental effort by clicking on one of the options of the rating scale. Subsequently, participants received the comprehension test. Each question was presented individually on the computer screen in a random order. Participants could answer the multiple-choice questions by clicking on the answer they believed to be correct. After finishing each question, participants could advance to the next question by clicking a 'next-button'. Participants could not go back to questions they had already answered. Subsequently, a transfer test was given. As with the comprehension questions, each question was presented individually on the computer screen in a random order. Participants could answer the transfer questions by typing their answer in an on-screen textbox by using the keyboard. There was no time limit for the tests and each test was followed by a mental effort rating. The total procedure lasted for about 45 minutes.

Analysis

The comprehension questions were scored by adding up the correct responses for each question. Each right answer yielded 1 point. Separate counts were made for questions concerning the cued process (i.e. the valves of the heart) and the questions concerning all other processes. This resulted in two comprehension scores: a comprehension score (between 0 and 10) for questions about the cued process and a comprehension score (between 0 and 28) for all other comprehension questions. Cronbach's alpha for the overall comprehension test was 0.70, which can be considered an acceptable degree of internal consistency in this study given that a priori we did not expect the internal consistency to be very high because the animation lasted only 60 seconds and involved many simultaneously occurring processes, so it was assumed that participants would differ in the information that was extracted.

For the transfer test, we developed a scoring form with 48 core idea units distributed over all questions. Scoring was done by counting for each question how many of the core idea units per question were included in the participant's responses. As with the comprehension test, separate counts were made for questions concerning the cued process (i.e. the valves of the heart) and the questions concerning all other processes. This resulted in two transfer scores: a transfer score (between 0 and 11) for questions about the cued process and a transfer score (between 0 and 37) for all other transfer questions. Cronbach's alpha for the overall transfer test was 0.84.

A scorer who was unaware of treatment condition, scored all responses on the comprehension test and the transfer test, for each participant. A randomly selected subset of 25% of the tests was scored by a second scorer. Agreement between both scorers was 100% on the comprehension test, and 97% on the transfer test. Based on these results, it was concluded that the scoring procedure was sufficiently reliable and the scores from the first scorer could be used.

Results

The dependent variables were comprehension score for questions about the cued process, comprehension score for all other comprehension questions, transfer score for questions about the cued process, a transfer score for all other transfer questions, and mental effort score during the animation and the mental effort during the comprehension test and the transfer test. The scores on the two comprehension measures, the two transfer measures, and the three mental effort measures were subjected to separate multivariate analysis of variance (MANOVA) with Cueing (Yes vs. No) as the between-participants factor. Additionally, separate univariate analysis of variance (ANOVA) was conducted. All statistical tests were carried out using a 0.05 significance level. Effect sizes were calculated using Cohen's measure of effect size (indicated by d). According to the conventions defined by Cohen (1988) *d* values of 0.2, 0.5, and 0.8 correspond to small, medium, and large effect sizes respectively.

Outcome measures

The MANOVA on the comprehension scores reveals a significant effect of cueing, Wilks' $\lambda = 0.85$, $F(2, 37) = 3.29$, $p<0.05$. The results shown in Table 1, which provides the means and standard deviations of the univariate analyses on comprehension and transfer for the two conditions, indicate that participants in the CA-group performed better than the participants in the NC-group with respect to the comprehension questions about the valves, $F(1, 38) = 5.21$, $MSE = 1.39$, $p<0.05$, $d = 0.72$. Interestingly, results on the comprehension questions about the other processes also indicate an advantage for the CA-group as compared to the NC-group, $F(1, 38) = 4.29$, $MSE = 16.39$, $p<0.05$, $d = 0.65$.

In addition, the MANOVA on the transfer scores also indicates a significant effect of cueing, Wilks' $\lambda = 0.84$, $F(2, 37) = 3.66$, $p<0.05$. As can be seen in the univariate outcomes shown in Table 1, a cueing effect was found for the transfer questions concerning the valves, with the CA-group scoring significantly better than the NC-group, $F(1, 38) = 5.28$, $MSE = 3.45$, $p<0.05$, $d = 0.73$. Participants who received the cued animation not only obtained higher learning outcomes on the questions concerned with the valves system than the participants who received an uncued animation, but also on transfer questions concerning the other processes of the cardiovascular system, $F(1, 38) = 7.09$, $MSE = 18.27$, $p<.05$, $d = 0.84$, which indicates a strong effect of cueing on uncued processes of the animation.

Table 1 *Mean scores (and standard deviations) on the comprehension test and the transfer test for the CA-group and the NC-group*

	CA-group		NC-group	
	Number Correct	*SD*	Number Correct	*SD*
Comprehension				
Valves (0-10)	6.7	1.3	5.9	1.0
Other processes (0-28)	15.5	3.7	12.9	4.3
Transfer				
Valves (0-11)	3.1	2.1	1.7	1.5
Other processes (0-37)	10.4	4.6	6.8	4.0

To determine the cognitive load of the different tasks imposed on the learner, mental effort was measured after studying the animation and after each test. The MANOVA on the mental effort measures reveals no significant effect of cueing, Wilks' $\lambda = 0.96$, $F(3, 36) = 0.53$, $p>0.05$. In the first row of Table 2, which displays the means and standard deviations of the univariate analyses for the mental effort scores after completing each task for the two conditions, it can be seen that mental effort while studying the animation did not significantly differ between the CA-group and the NC-group, $F(1, 38) = 0.17$, $MSE = 2.36$, $p>0.05$. When looking at the mental effort measures after the comprehension and transfer test, which are displayed in the second and third row of Table 2, results reveal that none of these measures significantly differed between the two conditions, $F(1, 38) = 0.99$, $MSE = 2.05$, $p>0.05$ and $F(1, 38) = 0.04$, $MSE = 2.78$, $p>0.05$, respectively.

Table 2 *Mean mental effort scores (and standard deviations) for the CA-group and the NC-group*

	CA-group		NC-group	
	M	*SD*	*M*	*SD*
Mental effort animation (1-9)	4.4	1.5	4.6	1.6
Mental effort comprehension (1-9)	6.3	1.4	6.7	1.5
Mental effort transfer (1-9)	6.1	1.4	6.2	1.9

Discussion

This study investigated whether studying a complex animation with a visual cue would result in better comprehension and transfer performance than when the animation was studied without a visual cue. The results confirmed the hypothesis, indicating that cueing can be successfully used as a technique to enhance performance when learning from animations without significant differences between conditions in mental effort. By guiding attention to the relevant aspects in the animation, working memory resources can be allocated to learning more efficiently. Also, the results on the transfer test suggest that cueing assisted learners in forming more coherent schemata, than when the animation is not cued. Thus, learners benefited from cueing and were able to process the presented information satisfactorily because cueing provided attentional guidance that may have reduced visual search. However, to support this claim additional research is needed, for example by varying visual search complexity of the animation or by applying an eye-tracking methodology to see how cueing affects overt attention allocation. These findings extend prior research on cueing suggesting that visual cueing not only works when applied to texts (Lorch, 1989; Lorch et al., 1993), or the combination of pictorial and textual information (Kalyuga et al., 1999) but also when applied to animations that do not involve any narrations. The question whether cueing also enhances learning in animations that contain narrations remains to be addressed.

Contrary to our expectations, we did not find a decrease in mental effort while studying the animation when focusing attention in that animation, which is consistent with results obtained by Tabbers and colleagues (2004). In the present study, the mental effort scores were fairly low. This could be an indication that the animation was not complex enough or that people invested too little effort. However, low or average mental effort scores are commonly reported (Mayer & Chandler, 2001). Given that the scores on the comprehension and transfer test are not very high and that the present animation included several simultaneously occurring events and, hence, consisted of a reasonable degree of complexity, this first explanation does not seem very likely. Alternatively, our latter explanation seems a more plausible explanation as it is in line with the idea that motivational factors may play a crucial role in learning by mediating the amount of cognitive processing (Moreno, 2006).

Interestingly, results revealed that cueing not only improved comprehension and transfer for the cued process, but also enhances knowledge of the uncued processes. These results go beyond our hypothesis that cueing one process within an animation leads to better comprehension of that process than when that process is not visually highlighted. Despite the fact that the mechanisms behind cueing in animations are far from well known, several interpretations can be offered to explain this result. For example, understanding the workings of the valves system might make other processes easier, by way of functionality. That is, the valves system is a special process in the sense that it is located in the middle of the heart and serves a central function in the cardiovascular system, for example, in regulating the direction and trajectory of blood flowing in and out off each chamber of the heart. So, if the valves are understood, other processes might become easier to understand as well (i.e. the direction of the blood flow). However, we use CLT to interpret the present findings and contend that, when studying a cued animation more cognitive resources can be allocated to germane load instead of extraneous load, that is, processes relevant for learning. At a perceptual level, the visual cue divides the animation in a cued segment and an uncued segment. At a cognitive level, this may have consequences on the allocation of attention, and hence, the distribution of working memory resources. That is, as each segment can be processed in isolation, less working memory capacity is used, which in turn can be used for the construction and integration of elaborated schemata. This seems a plausible explanation, which also acknowledges the finding that cueing also enhances learning outcomes for the uncued elements. Further research is needed to test this account, for example by shortening the time to study the animation to see if mental effort is reduced when no time is given to study uncued processes and integrate cued and uncued elements.

Our results and interpretations are limited by the learners, the nature of the materials, and the learning situation. First, the learners had at least some basic understanding of the cardiovascular system and hence can be characterized as having average background knowledge. Based on the expertise reversal effect (Kalyuga, Ayres, Chandler, & Sweller, 2003) it would be reasonable to assume that cueing has differential effects on more and less knowledgeable learners. Second, the animation was short, involved no narrations, involved only one cued process and the speed of the animation was not chosen on theoretical grounds but it was based on the standard speed of the software package with which the animation was developed. It is not clear whether the present results would also apply to animations that are longer, involve narrations, contain more than one cued process, and are played at different speeds. For example, it could be argued that playing the animation at different speeds differentially affects the effectiveness of cueing, with fast animations urging the need for a visual cue to keep track of all changes while in a slow animation a cue is unnecessary in guiding attention because all elements can be attended to appropriately. More research is needed to further investigate these issues as potential moderating factors. Third, the animation was shown just once and lacked the opportunity to interact, which seems a rather artificial situation. In general, animations in educational practice involve some kind of interactivity (e.g. stop, and replay) and can be viewed multiple times. It remains to be addressed whether the same results are obtained when these issues are taken into account. Overall, these limitations put some constraints on the generalizability of our findings. Future research is needed to determine whether visual cueing differentially affects learners (such as learners with different levels of expertise), different kinds of learning materials (such as animations with different speeds), and other learning situations (such as animations incorporating interactivity).

From a practical point of view, this study opens a new view on learning from animations and the design of multimedia instructions. The cueing-effect obtained in this study has a direct implication for the design of animations. Learners often are unable to process the presented information in an animation and have difficulties extracting relevant information from it. While it is possible to use a simplified static picture instead of an animation to promote comprehension (Butcher, 2006), valuable information such as timing aspects and dynamics in an animation are lost when reducing complexity. Based on the present study we provide a new way of reducing the visual complexity of animations in order to promote learning in the form of cueing. Cueing can play a crucial role in the comprehension of an animation by a more efficient use of working memory resources. Moreover, cueing may have the additional advantage of organizing information presented in the animation. In conclusion, incorporating a visual cue in the design of an animation seems an interesting tool for instructional designers to enhance learning from an animation.

Chapter

3

Attention cueing in an instructional animation: The role of presentation speed[2]

[2] This chapter is submitted for publication as: De Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2009). *Attention cueing in an instructional animation: The role of presentation speed.* Manuscript submitted for publication.

Abstract

Research has shown that guiding learners' attention in instructional animations by cueing does not necessarily improve conceptual understanding. This study investigated whether the number of elements that should be processed per unit of time influences the instructional effectiveness of attention cueing by showing a cued or an uncued animation about the cardiovascular system at a high or at a low presentation speed. It was hypothesized that cueing would be most helpful for learning when the animation was shown at a high presentation speed rather than at a low presentation speed. Unexpectedly, students showed the same performance on comprehension and transfer tests irrespective of cueing and the animation's presentation speed. However, students in the low presentation speed groups invested more mental effort to obtain this performance than students in the high presentation speed groups. An animation's information density may therefore not be essential for improving the effectiveness of cueing on learning.

Introduction

Dynamic visualizations such as animation or video have become a popular means for providing instruction (Ayres & Paas, 2007; Mayer, 2005). However, the majority of studies comparing dynamic visualizations to static visualizations for teaching change-related information have not shown advantages of animations, that is, learners do not seem to construct more accurate mental representations of a system's dynamics from animations than from static visualizations (for a review see Tversky, Morrison, & Bétrancourt, 2002).

According to Tversky et al. (2002), the explicit depiction of movements and changes in animations may be problematic rather than helpful for understanding, because the information is presented in such a way that it can not be accurately perceived and understood (cf. apprehension principle). Cognitive load theory (CLT; Paas, Renkl, Sweller, 2003), for example, argues that due to the limitations of working memory learners may not be able to deal with the high information load of animations, which might hamper understanding of the content. Complex animations often simultaneously show a large number of interacting elements that may differ substantially with respect to their perceptual characteristics such as color and form. Consequently, learners who are unfamiliar with respect to the subject-matter will have to spatially and temporally split their visual attention over the visual display and search for an animation's crucial parts, their characteristics and the various relations that exist among them. In addition, not all parts and relations of an animation will be equally important for constructing an accurate mental representation. The information in some parts or locations of an animation may be more relevant than others for developing a deeper understanding of the depicted system. Deciding which parts contain relevant information and thus deserve attention may keep learners from engaging in genuine learning activities and therefore may cause high ineffective or extraneous cognitive load for inexperienced learners (Paas et al., 2003; Sweller, van Merriënboer, & Paas, 1998). This may especially be the case in situations where the most conspicuous aspects of animations do not necessarily represent the most relevant information (Lowe, 2005). Therefore, trying to understand complex animations with many (irrelevant) salient details and complex relations in which no attempts have been made to emphasize relevant aspects might require so much cognitive resources that little remains for processing the actual subject-matter (Ayres & Paas, 2007). Consequently, learners may fail to extract essential information from the display that is required for building a satisfactory mental representation of the content depicted in the animation.

Directing learners' attention with cues

Hence, learners might be expected to significantly improve their understanding of an animation when ineffective cognitive load due to misdirection of attention is reduced and enables learners to focus their attention on the right parts in order to select and further process the required information (Lowe, 2008). A recent suggestion for improving learning from animations, therefore, focuses on the inclusion of attention cues (e.g., arrows, color-coding) that are aimed at explicitly directing learners' attention to the relevant aspects of an animation (Mayer & Moreno, 2003). By emphasizing crucial parts of an animation, the learners' engagement with the demanding visual search processes to locate task-relevant information and its associated ineffective cognitive load is minimized. Thereby, the amount of working memory resources that can be used for activities that help learners in trying to understand the content and the underlying relations is supposed to be increased.

Several recent studies that have investigated the instructional effectiveness of attention cueing in animations have shown that attention-directing cues (i.e., arrow-cues and spotlight-cues) can effectively (re)direct the learners' attention towards specific elements in an animation (De Koning, Tabbers, Rikers, & Paas, in press; Kriz & Hegarty, 2007). Cues thus increase the possibility that task-relevant elements or regions receive the learners' attention. However, increased attention for cued locations in animations does not necessarily coincide with a better conceptual understanding of the depicted information as evidenced by the mixed findings for the effects of cues on learning from animation (for an overview see De Koning, Tabbers, Rikers, & Paas, 2009). Whereas some studies have shown improved retention and transfer performance with a cued animation (Boucheix & Lowe, in press; De Koning, Tabbers, Rikers, & Paas, 2007), other studies have failed to find better learning outcomes for cued animations compared to uncued animations (De Koning et al., in press; Kriz & Hegarty, 2007; Mautone & Mayer, 2001).

One possible explanation for the failure to obtain an animation cueing effect on learning is that the animations that were used to examine the effects of cueing represented no or only a few simultaneous changes and thus did not impose considerable demands on learners' attentional processing to find relevant information. Moreover, as learners could spent their effort in processing the animations' (few) interacting elements, they might also have experienced little problems in trying to understand the animation. So, the animations did not require much mental effort and therefore did not need the extra guidance of cues to direct attention and reduce ineffective cognitive processes (cf. Mautone & Mayer, 2001). In a study by Mautone and Mayer (2001), for example, the animation contained relatively few (distracting) elements and learners could easily discern the animation's structure and relations. The animation thus required less of the learners' cognitive resources and, therefore, cues were irrelevant or redundant for decreasing extraneous processing. This suggestion is consistent with studies on cueing in texts and/or static visualizations, which have shown that adding cues to texts and/or visualizations is most beneficial for learning when the materials have a high degree of complexity (Jeung, Chandler, & Sweller, 1997; Lorch & Lorch, 1996). These observations suggest that cueing may be especially effective for improving animation-based learning when animations have a degree of complexity that learners can not manage on their own, such as when the depicted events in animations occur at a fast pace and consist of an interplay of several relevant and irrelevant interacting elements.

Complexity and presentation speed in animations

The experimental work reported in the current study examined whether the extent to which cues facilitate learning from animations is influenced by the number of elements that have to be processed per unit of time in order to understand the content. The feature of animations to show change over time at different speed levels enables researchers to elegantly manipulate the amount or density of information that should be processed at a certain moment in time and thereby the load that is imposed on the learners' perceptual and cognitive resources without the removal or addition of elements from the content, by presenting an animation at a lower or at a higher presentation speed. Slowing down an animation's presentation speed may allow learners to process more of the available information and reduce the possibility of missing relevant parts because they have more time and working memory resources available for exploring the animation in considerable detail. The low presentation speed may allow learners to construct a mental representation of the local parts, which then can be integrated into an integrated mental model (Meyer, Rasch, & Schnotz, in press). In contrast, increasing presentation speed may force learners to quickly and repeatedly decide which information requires intentional processing as the same amount of information is presented in less time. Consequently, learners may miss or only partially process information and may have little or no time and working memory resources available to relate and integrate current with previous information in order to comprehend the animation (Ayres & Sweller, 2005). In this study, we therefore refer to an animation with a low presentation speed as corresponding to a 'low load animation', whereas an animation with a high presentation speed is referred to as corresponding to a 'high load animation'.

Some recent studies investigating the effects of an animation's presentation speed on learning have already indicated that presentation speed may have a positive influence on understanding of the depicted content (Fischer et al., 2008; Fischer & Schwan, in press; Meyer et al., in press). For example, Fischer et al. (2008) found evidence that increasing the presentation speed of a pendulum clock animation in order to make the movements of the crucial clock parts visible improved learning compared to a normal presentation speed. These studies have manipulated presentation speed in order to make information in an animation available that otherwise could not be perceived. The present study, however, investigated whether varying presentation speed as a way of manipulating the number of already perceivable elements that should be processed at the same time in animations influences the effectiveness of cueing.

Participants were shown a cued or an uncued animation about the cardiovascular system either at a high speed (i.e., high load animation) or at a low speed (i.e., low load animation). In the cueing conditions, a single subsystem of the cardiovascular system was cued to avoid ordering and segmentation effects as a result of cueing different parts serially. Based on the suggestion that cueing may be most effective for facilitating learning from animations with a high number of simultaneously presented interacting elements, it was expected that the requirement for help from cues was highest when the animation was shown at a high presentation speed. Cueing should in this situation facilitate the identification of specific elements by drawing attention to them (Kriz & Hegarty, 2007). By minimizing the necessity to quickly search for relevant information the possibility that learners may use their available working memory resources for trying to understand the elements and their relations is increased. However, if the animation has a low number of interacting elements, that is, when the animation is presented at a low speed, the presentation speed of the animation is better aligned with the limits of the learners' processing capacities and they may thus have more time and working memory resources available for trying to understand the content and cues may therefore not be needed to assist them in developing an accurate understanding from the animation. Consequently, we predicted a significant interaction between the presentation speed of the animation and cueing, indicating that learners studying an animation at a high presentation speed would benefit from cueing as indicated by higher performance on comprehension and transfer tests, whereas learners studying an animation at a low presentation speed would not be able to profit from cueing and thus would not enhance their performance on these learning tests.

Method

Participants and design

Participants were 84 psychology undergraduates (9 males and 75 females) from the Erasmus University Rotterdam. Their mean age was 19.98 years (*SD* = 3.48). All were native Dutch speakers and received partial course credit for their participation. Participants had normal or corrected to normal vision, were unaware as to the exact purpose of the study, and gave informed consent. None of the participants had taken college level biology classes, but all had taken introductory courses on biology in high school that included the cardiovascular system and its basic components.

The experiment conformed to a factorial design with the factors cueing (yes vs. no) and presentation speed (low vs. high). Participants were randomly assigned to one of four conditions, in such a way that there were 21 participants in the condition with cueing and with a low presentation speed, 21 in the condition with cueing and with a high presentation speed, 21 in the condition without cueing and with a low presentation speed, and 21 in the condition without visual cueing and with a high presentation speed.

Materials and apparatus

The materials consisted of a participant questionnaire, an animation, a mental effort rating scale, a comprehension test, and a transfer test. They were developed with Macromedia Flash 7.0 (Macromedia, 2004) and were presented on a 19" LCD color computer screen with a resolution of 1280 x 1024 pixels. All data were automatically recorded and saved in a connected database.

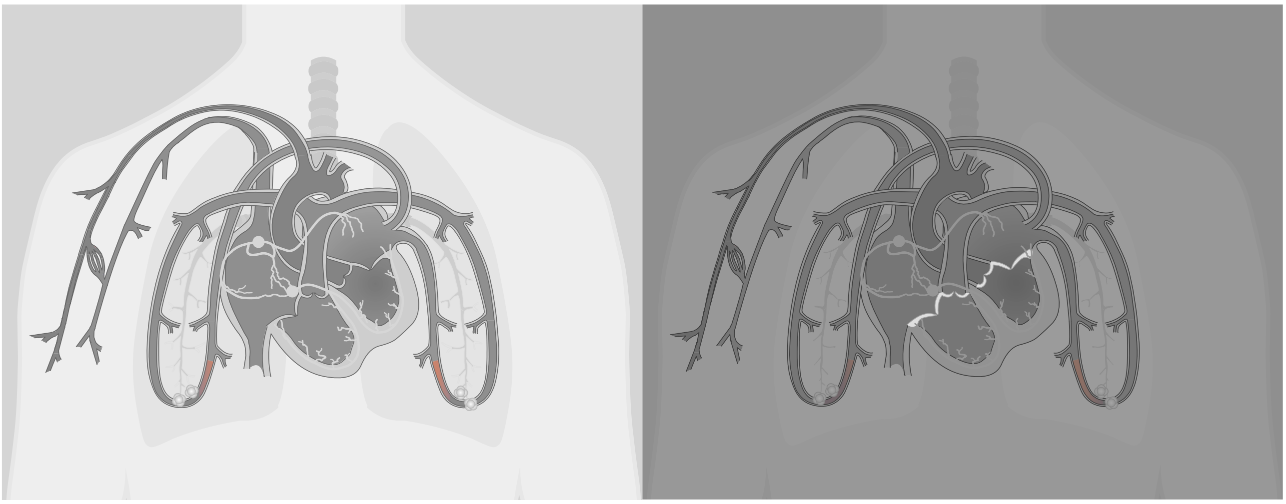
Participant questionnaire

The participant questionnaire, which was based on Mayer and Moreno's (1998) questionnaire, consisted of questions concerning the participant's gender, age, and years of university education. Furthermore, participants were asked to rate their prior knowledge of the cardiovascular system with one Likert-type item on a 5-point scale ranging from 1 (very little) to 5 (very much). Four other questions, that were presented in the form of a 4-item checklist, required the participants to indicate their experience with biology and the cardiovascular system. For example, participants were asked whether they had followed biology classes during their secondary education or whether they knew someone in their inner circle with a heart condition. For three of the checklist items a score between 0 and 2 could be obtained, whereas for one of the checklist items a score between 0 and 3 could be obtained. Therefore, the total score for all four checklist items together ranged between 0 and 9. All five prior-knowledge/experience items were added up to get a score, indicating overall knowledge of the cardiovascular system, ranging from 1 (no experience) to 14 (high experience). Analysis of the prior-knowledge score indicated no significant differences between the cued-fast condition ($M = 4.48$, $SD = 3.23$), the cued-slow condition ($M = 4.95$, $SD = 3.26$), the uncued-fast condition ($M = 4.86$, $SD = 2.61$), and the uncued-slow condition ($M = 4.76$, $SD = 3.14$), $F < 1$, *ns*.

Animation

Four versions of an animation illustrating the functioning of the human cardiovascular system were used in this study (see Figure 1a). The content in all versions was identical. That is, all four versions depicted the simultaneous dynamics of the five main subsystems of the cardiovascular system: The electrical system, the pulmonary circulation, the circulatory system, the systemic circulation, and the valves system. Each subsystem has unique dynamic characteristics and serves a specific role in the cardiovascular system. However, despite their individual properties and purposes, the subsystems are largely dependent on each other to let the cardiovascular system function correctly. In short, the animation showed how and where blood flows in the heart, where exchange of oxygen and waste products takes place, how the heart contracts, and how the heart valves and electrical system work. In total, the animation showed six cardiac cycles. Prior research with the same learning materials has demonstrated that this is sufficient to reach quite a good understanding of the dynamics presented in the animation (De Koning et al., 2007). The animation was presented without accompanying written or verbal descriptions or labels. Furthermore, it contained no pauses, learners could not control its speed, its direction, and they could not stop the animation.

Despite identical content in all conditions, the four versions of the animation differed in two ways. First, the animation was either presented at a low presentation speed or at a high presentation speed. For the slow-paced animations, presentation speed was set at 4 frames per second and for the fast-paced animations presentation speed was set at 24 frames per second. Because the same number of cardiac cycles was presented in all versions of the animation to keep the amount of information equivalent (i.e., 6 cycles), the changes in presentation speed led to different presentation durations of the slow-paced and the fast-paced animations, with the slow-paced animation lasting 180 seconds and the fast-paced animation lasting 30 seconds.



a **b**

Figure 1 *Screen-examples of the uncued (a) and the cued (b) animation of the cardiovascular system*

Second, the difference between the cued and the uncued animations was that in the cued version the valves system was cued. A complete subsystem was cued to increase the chance that task-relevant information was processed by directing learners' attention to specific parts of the animation without emphasizing only small fragments of the content. The valves system was chosen as the process to be cued, because this system is an important functional part of the cardiovascular system, but is not very salient (Lowe, 1999). Cueing was done by decreasing the luminance of all elements in the animation except the cued subsystem (see Figure 1b). This visual contrast enables the cued subsystem to stand out against the rest of the animation and, therefore, to become more noticeable. Despite this change, all uncued elements of the animation were still visible and could be attended to. In all cueing conditions, the cue appeared on the screen one cardiac cycle after the start of the animation to ensure that participants would notice the visual manipulation.

Mental effort

The mental effort measure used in this study was a 9-point subjective rating scale, ranging from very, very low mental effort (1) to very, very high mental effort (9), and was developed by Paas (1992). The scale's high reliability and validity, and its non-intrusive nature make the scale a useful measure of perceived working memory load (Paas, 1992; Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

Learning performance

To assess the participants' understanding of the cardiovascular system, a set of 38 comprehension questions and 10 transfer questions were used. All questions covered information that was presented in the animation or tested the knowledge that could be inferred from it. Sample questions for the comprehension and transfer tests can be found in De Koning et al. (2007).

The comprehension questions consisted of multiple choice items with four alternatives. Ten questions were concerned with the structural and dynamic aspects of the valves system, whereas the remaining 28 questions dealt with this information for all other subsystems of the cardiovascular system. To minimize the risk that questions were misinterpreted or not fully understood, minimal use of terminology was made or pictures were added that referred to elements mentioned in the question. Test items were only pictorial if the questions were difficult to interpret with text alone or to clarify a concept. For example, one comprehension question asked participants to choose the picture that correctly shows the direction of blood flow out of four pictures.

The transfer test consisted of ten open-ended questions. Out of all transfer questions, two questions asked learners to reason about the functioning of the valves system. Reasoning about the rest of the cardiovascular system was covered by the remaining eight questions. Transfer items could only be answered correctly by applying the learned inferences about the cause-effect relations of the subsystems (i.e., cued parts) and, therefore, provides a good measure of the quality of the constructed representation (Mayer, 2001). An example of a transfer question is 'The workings of the electrical system can be divided into two steps. Explain why this is.'

Procedure

Participants were tested in groups up to four persons per session. They were seated at an individual computer and completed the experiment at their own pace. First, the participants filled out the demographic questionnaire. Then, they read instructions that stated that they should carefully study and try to comprehend the content of the animation, in order to be able to answer questions on subsequently given knowledge tests. Depending on the experimental condition, one of the four versions of the animation was then presented on the computer screen. The animation was followed by a frame asking the participant to indicate their invested mental effort by clicking on one of the options of the mental effort rating scale.

After a brief introduction to the test phase, participants completed the comprehension test. Comprehension questions could be answered by clicking on one of the four choice alternatives. Subsequently, participants were presented the transfer questions that could be answered by typing their answer in an on-screen textbox by using the keyboard. All test questions were individually and randomly presented on screen. Participants were able to sequentially move through the questions by clicking the 'next' button, but it was not possible to return to previously presented questions. Participants were allowed to take as much time as needed to answer each question. After each test, participants rated their invested mental effort to complete it. It took about 45 minutes to complete the entire experiment.

Analysis

Participants' performance on the comprehension and transfer items was scored blind with respect to experimental condition by two independent raters. For each correct answer to a comprehension item participants received one point, otherwise they received zero points. For all conditions, two comprehension scores were computed: A comprehension score (between 0 and 10) for items about the cued subsystem (i.e., valves system) and an overall comprehension score (between 0 and 28) for all other comprehension items. Cronbach's alpha for the overall comprehension test was .69. There was 100% agreement between raters on the comprehension test.

The transfer questions were scored by counting the number of idea units per question that were included in the participant's answer. To estimate the interrater reliability, we calculated Cohen's kappa on the pairs of scores (Cohen, 1988). The results revealed a high interrater agreement (k = .70). As with the comprehension test, for all conditions a transfer score (between 0 and 11) for items about the cued subsystem (i.e., valves system) and an overall transfer score (between 0 and 37) for all other transfer items were computed. Cronbach's alpha for the overall transfer test was .60.

Results

The scores on the two comprehension measures, the two transfer measures, and the three mental effort measures were subjected to separate multivariate analysis of variance (MANOVA) with cueing (yes vs. no) and presentation speed (low vs. high) as the between-subject factors. For all statistical tests, a significance level of .05 was applied. For any post-hoc analyses, we used analysis of variance (ANOVA). Effect sizes are expressed in terms of partial eta squared (partial η^2). Table 1 shows the mean scores and standard deviations on the dependent measures for all conditions.

Learning outcomes

The MANOVA on the two comprehension scores reveals no significant effect of cueing, Wilks' lambda = .96, $F(2,79) = 1.61$, $p > .05$. In addition, no significant effect of presentation speed was found, Wilks' lambda = .96, $F\ (2,79) = 1.52$, $p > .05$.

Furthermore, there was no significant interaction between cueing and presentation speed, Wilks' lambda = .99, $F\ (2,79) = .23$, $p > .05$. This suggests that increasing the animation's presentation speed did not have a different influence on the effectiveness of cueing than decreasing the animation's presentation speed.

Table 1 *Means (and standard deviations) of the dependent measures as a function of condition*

	Low presentation speed				High presentation speed			
	Cued		Uncued		Cued		Uncued	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Learning Outcomes								
Comprehension valves system (0-10)	6.38	2.27	6.10	2.32	5.95	2.09	5.05	2.22
Comprehension other subsystems (0-28)	14.95	4.89	15.90	4.93	13.90	4.59	13.71	4.19
Transfer valves system (0-11)	1.71	1.35	1.62	1.24	2.10	1.30	2.10	1.30
Transfer other subsystems (0-37)	9.48	5.42	9.86	5.86	10.19	3.97	10.29	4.56
Mental effort (ME)								
ME Animation (1-9)	5.57*	1.83	5.76*	1.84	4.71*	1.35	4.52*	1.72
ME Comprehension test (1-9)	6.90	1.30	7.00	1.41	6.71	1.23	6.81	1.69
ME Transfer test (1-9)	7.29	1.68	7.38	1.50	6.81	1.75	6.62	1.99

Note. * $p < .05$.

Furthermore, the MANOVA on the transfer test also shows neither an effect of cueing, Wilks' lambda = .99, $F < 1$, *ns*, nor an effect of presentation speed, Wilks' lambda = .97, F (2,79) = 1.14, $p > .05$. As with the comprehension test, the interaction between cueing and presentation speed was not significant, Wilks' lambda = .99, $F < 1$, *ns*. In short, the comprehension and transfer results show that increasing the animation's presentation speed, and hence its complexity, does not increase the effectiveness of cueing as indicated by the comprehension and transfer scores on the questions about cued information. In addition, presentation speed and cueing do also not seem to influence the understanding of uncued information.

Mental effort

The results on the mental effort scores, however, demonstrate a significant effect of presentation speed, Wilks' lambda = .87, F (3,78) = 3.94, $p < .05$, partial $\eta^2 = .132$. Post hoc analyses revealed that presentation speed significantly influenced the mental effort scores while studying the animation. When the animation was presented at a high speed participants reported less mental effort in studying the animation than when the animation was presented at a low speed, F (1,80) = 8.00, $MSE = 2.88$, $p < .05$, partial $\eta^2 = .091$. There were no significant differences in mental effort spent on the comprehension test, $F < 1$, *ns*, or in mental effort spent on the transfer test, F (1,80) = 2.67, $MSE = 3.02$, $p > .05$, as a result of varying the animation's presentation speed. Furthermore, the results did not show a significant effect of cueing on the mental effort scores, Wilks' lambda = .99, $F < 1$, *ns*. There was also no significant interaction between cueing and presentation speed, Wilks' lambda = .99, $F < 1$, *ns*.

Discussion

The present study examined whether the number of elements that should be attended to at once in animations by showing an instructional animation at a high or at a low presentation speed influences the instructional effectiveness of attention cueing. Our hypothesis that attention cueing would be more helpful for learning when the animation was shown at a high rather than at a low presentation speed (i.e., high vs. low load animation) was not confirmed. Rather, irrespective of the animation's presentation speed learners in both the cued and the uncued conditions were able to answer the comprehension and transfer questions about the cued part and those about the uncued parts of the cardiovascular system equally well. These findings do not seem to support the idea that simply increasing the number of relations that are presented at the same time in an animation by increasing its presentation speed makes attention cueing a more effective means for improving conceptual understanding just as increased complexity in static representations improves the instructional effectiveness of cueing (Jeung et al., 1997; Mautone & Mayer, 2001). However, in contrast to the De Koning et al. (2007) study, learning from the animation was not improved by cueing, and therefore the interaction between cueing and presentation speed may not have occurred. This suggests that the cueing effect observed by De Koning et al. (2007) is not very robust and may require a specific presentation speed of the animation. It is yet unclear what actually occurred during learning from the cued and uncued animation. For example, it is unknown to what extent learners engaged in the knowledge construction activities necessary for learning and whether the number of interacting elements that should be processed per unit of time played a crucial role in the learning process. Further research is required to investigate these aspects.

Furthermore, the fact that little was actually learned from the animation may also have contributed to our findings. In all conditions the performance on the comprehension test and even more so on the transfer test was quite low, suggesting that in any case learners were not well able to extract the main ideas from the presentation and to combine them into a coherent mental representation. Even learners who studied the animation at a low presentation speed and thus had more time to process the presented information did not differ from the high presentation speed conditions with respect to their learning performance. However, these learners reported higher cognitive load during the learning phase than those who studied the animation at a high presentation speed. Although this is not consistent with the predictions, cognitive load theorists could easily explain this finding post-hoc by arguing that in the low presentation speed groups learners had more time and invested more mental effort in activities that did not contribute to learning, that is, activities that imposed high extraneous cognitive load such as keeping information active in working memory, which may have resulted in less coherent mental representations and hence less efficient test performance (Ayres & Paas, 2007; Van Gog & Paas, 2008). Following this suggestion, the slow animation could have hindered learning as it may have imposed additional cognitive requirements due to a too low presentation speed.

On the other hand, the results also suggest that the requirement to simultaneously process a large number of interacting elements does not seem to pose working memory problems for learners in the high speed conditions, which is against the assumptions made by cognitive load theory. Of course, less cognitive load may be the result of not having invested enough mental effort required for building a coherent mental representation or have adopted a processing strategy to avoid information overload due to the (too) high speed of the animation (underwhelming, Lowe, 2004), which might explain the low scores on the comprehension and transfer test. Alternatively, increasing the animation's presentation speed may not have increased the animation's cognitive load and thus did not require more effort from learners to focus on the relevant information. It could also be that presentation speed only influences perceptual complexity and therefore does not really affect cognitive load in working memory. Moreover, DeLeeuw and Mayer (2009) have even suggested that learning from complex instructional materials may sometimes load perceptual rather than cognitive processes, but it is yet unclear what perceptual load exactly is, how it relates to cognitive load and how it influences the learning process. As our mental effort measure does not allow us to differentiate between the contributions of each type of cognitive load and does not involve a direct indication of the demands on perceptual processing, further research is required to shed more light on this issue.

Furthermore, the cues in this experiment focused attention on specific parts of the animation, which may have facilitated perceptual processing but may not have promoted understanding of the system (see De Koning et al., in press; Kriz & Hegarty, 2007). In line with this, Fischer and Schwan (in press) have argued that attention guidance may only improve learning from animations if it does not only focuses attention on local parts of an animation, but at the same time provides dynamic information about the underlying principles of the depicted system, such as when increased presentation speed makes learners aware that specific elements are moving instead of being static entities, which allows for easier perception and encourages learners to use this information for constructing or revising their mental representation (cf. Fischer et al., 2008). However, neither the cues nor the presentation speed were able to accomplish this, as only the number of already perceivable elements that were presented together in time was varied in the current animation. In addition, if uncued elements are required for developing an accurate understanding of the cued system and their interrelations with the uncued parts, the specific type of cueing through which the visibility of uncued elements in the animation was decreased might have hampered learning even further.

As the current study does not allow us to make any conclusions about the feasibility of each of these explanations, we recommend researchers to investigate in more detail how and to what extent animations, presentation speed, and cues influence cognitive load and meaningful cognitive processing activities and to what extent cognitive load theory may provide an appropriate account in these situations. For example, it could be investigated whether removing elements and/or relations from the content will yield results similar to those obtained in the present study. Another interesting issue for further research is the use of various presentation speeds. The current study has only investigated a low and a high presentation speed of an animation. However, several intermediate speed levels could have different perceptual and cognitive consequences and therefore need to be investigated in further studies (Meyer et al., in press). Moreover, further research is required to examine whether the present findings can be obtained in longer educational tasks, using different types of cueing (e.g., arrows), in more educationally valid research settings (i.e., regular classroom), and with different types of animations such as animations with textual explanations, non-cyclical animations, or animations that allow learners to control the presentation).

In sum, the results of this study tentatively suggest that improving the effectiveness of cueing in order to enhance learning from animations may require more than simply increasing the number of elements that should be processed at once by raising an animation's presentation speed. Other factors may also be important in determining how learning from cued animations might be improved. For example, the observation that in this study learners do not seem to learn much from the animations suggests that it may be useful to gain more insight into what constructive activities learners engage in while studying cued and uncued animations and to find ways for how these activities can best be supported to facilitate the construction of an adequate dynamic mental representation. In conclusion, more precise knowledge is needed about the perceptual and cognitive effects that cueing and altered presentation speeds in animations might have on learning and mental effort so that we can discover how to design animations to increase learning performance and how to instruct or support learners to learn from animations more effectively.

Chapter

4

Attention guidance in learning from a complex animation: Seeing is understanding? [3]

[3] This chapter will be published as: De Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (in press). Attention guidance in learning from a complex animation: Seeing is understanding? *Learning and Instruction.*

Abstract

To examine how visual attentional resources are allocated when learning from a complex animation about the cardiovascular system, eye movements were registered in the absence and presence of visual cues. Cognitive processing was assessed using cued retrospective reporting, whereas comprehension and transfer tests measured the quality of the constructed representation. Within the framework of Cognitive Load Theory, visual cues highlighting the subsystems of the heart were hypothesized to guide attention, reduce visual search and extraneous cognitive load, and enhance learning. As predicted, learners looked more often and longer at cued parts. However, we found no effects of cueing on visual search and cognitive load. With respect to cognitive processing, performance differences were found on the number of statements in the learners' verbal reports. These findings suggest that visual cueing can guide attention in an animation, but other factors are also important in determining the effectiveness of visual cues on learning.

Introduction

In complex instructional animations learners are challenged to extract relevant information from a visual display, select corresponding parts of information, and integrate all of these elements into a coherent representation (Mayer & Moreno, 2003). This is a difficult task, as important information is briefly presented in successive frames and needs to be kept active in working memory to integrate it with earlier presented information, imposing a high cognitive load on the learners' cognitive system (Paas, Renkl, & Sweller, 2003). Empirical findings as well as theoretical considerations have led to various design guidelines that take into account the processing limitations of working memory to manage this high cognitive load and foster learning from animations (Mayer, 2001; Paas et al., 2003).

Most of the current knowledge regarding animations and learning, however, is based on product-related measures (e.g., comprehension and transfer tasks), from which attentional and cognitive task demands are inferred. Much less is known about how learners actually attend to instructional animations, that is, the real-time perceptual and cognitive processes involved. It is argued that the use of more direct process-related measures could advance research on animations by testing specific claims about the perceptual and cognitive characteristics of an animation or by directly investigating the psychological basis for instructional design guidelines. The present study was designed to evaluate how attention guidance affects processing of an animation by applying the process-related methods of eye tracking and cued retrospective reporting (Van Gog, Paas, Van Merriënboer, & Witte, 2005).

Learning from instructional animations

To derive meaning from an animation, learners have to construct a mental representation that accurately represents the content depicted in the visualization. Animations are supposed to be superior to static graphics, especially when learning concerns a chain of events in dynamic systems. Animations do not only depict objects, they also provide information concerning object changes and their position over time (Rieber, 1990). However, as Tversky, Morrisson, and Bétrancourt (2002) have pointed out, learners often fail to process animations effectively, resulting in no advantage compared with static visualizations (but see Höffler & Leutner, 2007). Learning from animations often fails because complex perceptual and cognitive processing overwhelms the learner's limited processing capacities (Lowe, 1999).

Ayres and Paas (2007b) have argued that most animations are not designed with the limited capacity of working memory (WM) in mind and therefore may interfere with the learning process. Cognitive Load Theory (CLT; Paas et al., 2003; Sweller, 1999) provides a theoretical framework that may offer a way of dealing with these WM limitations by instructionally controlling the demands of complex instructions. Three categories of cognitive load can be identified when learning from complex tasks: intrinsic, extraneous, and germane cognitive load. Intrinsic cognitive load depends on the number of information elements and their interactions that must be processed simultaneously in WM to understand the learning material. Extraneous cognitive load is determined by the activities required from learners that do not contribute to learning, but instead reduce WM capacity available for learning activities. Finally, germane cognitive load is generated by mental activities required for the construction and automation of schemata in long-term memory (see for a more detailed discussion on the different forms of cognitive load, Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

According to CLT, animations often create a high extraneous load because learners must split their visual attention between the visualization and accompanying text (*inter*-representational) and/or within the visualization (*intra*-representational, Lowe, 1999). In eye movement research, there are an increasing number of studies focusing on the perceptual and cognitive processes of mentally integrating different representations (i.e., text and picture; Graesser, Lu, Olde, Cooper-Pye, & Whitten, 2005; Hegarty, 1992; Holsanova, Holmberg, & Holmqvist, in press; Schmidt-Weigand, Kohnert, & Glowalla, in press; Schwonke, Berthold, & Renkl, in press). However, very little research has focused on how learners attend to instructional animations without text.

Animations depicting the functioning of technical or biological systems typically show several elements simultaneously that might change with respect to position, color, and orientation. The high degree of visual complexity due to the high information load and the distributed nature of the presentation may be perceptually and cognitively overwhelming (Lowe, 2003). The main processing of the visual system is limited to information, which is in foveal vision, so that learners cannot attend in one fixation to all information from a complex instructional animation. Consequently, only a subset of the presented information will receive attention and serve as the foundation for subsequent cognitive processing.

Constructing a mental representation of the content depicted in a complex animation initially requires effective search processes, that is, success in selecting and extracting task-relevant information. However, by requiring visuo-spatial resources to control the execution of eye movements, the process of locating task-relevant information creates extraneous load because WM resources may be diverted away from main learning activities (Jeung, Chandler, & Sweller, 1997). This especially holds for novices who lack relevant knowledge to guide their attention (see Canham & Hegarty, in press).

Moreover, the possibility of missing key information increases when the most salient elements do not correspond to the thematically relevant elements (Boucheix, Lowe, & Soirat, 2006; Lowe, 1999). Limiting the search space of the display by directing learners' attention to specific parts of an animation inevitably differentiates between relevant and irrelevant parts. This provides an opportunity to reduce visual complexity, creates a situation in which it is more likely that visual search and hence extraneous load are reduced, and engagement in essential processing activities are more likely to occur.

Attention guidance

Attention guidance techniques, such as cueing, have been used successfully to improve the learners' understanding of specific aspects of the display (De Koning, Tabbers, Rikers, & Paas, 2007; Mayer & Moreno, 2003; see also Boucheix & Lowe, in press). For example, in a study by De Koning et al. (2007), it was shown that increasing the visual salience of task-relevant information in an instructional animation through a spotlight-cue (i.e., luminance contrast), improved comprehension and transfer performance. Further evidence that attention-directing perceptual cues in a visualization can affect cognition, comes from a study by Grant and Spivey (2003). They have showed that solving an insight problem was facilitated when learners viewed a static diagram where critical information was made visually more salient. It is important to note that in these studies it could only be inferred that learners were focusing on the correct elements in the dynamic visualization. In the study of De Koning et al. (2007) only performance measures were used and in the Grant and Spivey (2003) study eye tracking was used but only as a means to identify critical features in the display. They did not, however, examine the actual viewing pattern during the problem-solving process when a perceptual cue was present to direct learners' attention to critical elements.

A first attempt to study real-time viewing patterns while visually cueing a complex instructional animation was made by Kriz and Hegarty (2007). In this study, eye movements were measured while learners studied an interactive animation depicting the mechanics of a flushing cistern that did or did not contain visual cues (i.e., arrows pointing to relevant information). Interestingly, results revealed that although these cues directed more attention to task-relevant information, this did not result in a better understanding of the presented information. On the other hand, the De Koning et al. (2007) study showed that learners benefited from visual cueing, suggesting that it did improve processing. However, direct evidence regarding the perceptual and cognitive processes that underlie this positive effect of attention cueing is lacking. Therefore, our main question is whether spotlight-cueing enables learners to focus on specific parts of an animation, which may help learners in reducing their visual search and extraneous cognitive load.

The present study

In the present study, we replicated the methodology previously used by De Koning et al. (2007), now adding process-related measures to examine how spotlight-cueing influences perceptual and cognitive processing when learning from an animation. Learners viewed an animation of the cardiovascular system with or without a spotlight-cue on the valves of the heart. However, in the De Koning et al. (2007) study only a single visual cue was used. One might argue that the effect of cueing would be larger when multiple visual cues are presented that highlight all parts of the cardiovascular system. That is, some subsystems are dependent on the functioning of another subsystem and, therefore, cueing all subsystems might further improve understanding. For example, by cueing the transportation of oxygen into the lungs (circulatory system) before oxygenation occurs in the alveoli (pulmonary circulation), learners may establish a link between these subsystems. Therefore, we also included a condition with multiple visual cues.

To investigate overt attention allocation, we registered the eye movements of learners while they viewed the animation. Furthermore, to get more information about which cognitive processes occur during learning, learners retrospectively reported the thoughts they had while studying the animation using a record of their own eye movements as a retrieval cue (i.e., cued retrospective reporting, Van Gog et al., 2005). Combining measures of eye tracking and verbal reporting allows for making inferences about what information is attended to in a cued and an non-cued animation and how this information is interpreted by the learner. Furthermore, the combining can reveal relatively small differences in knowledge acquisition (Van Gog et al., 2005), which may be especially helpful in examining the underlying processes that are responsible for the small but positive effects of visual cueing.

Hypotheses

For all hypotheses, it is important to note that the main comparisons are between the cued conditions (i.e., single-cueing and multiple-cueing condition) and the no-cueing condition.

It was hypothesized that, over the time course of the animation, cueing leads to an overall shift of attention distribution over the different subsystems, measured by the proportion of the number and duration of fixations on each of the subsystems (Hypothesis 1a). More specifically, it was hypothesized that, in line with Kriz and Hegarty (2007), visual cueing directs attention to the cued part yielding, compared to the no-cueing condition, proportionally more and longer fixations on the valves system (i.e., cued subsystem) in the single-cueing condition (Hypothesis 1b) and proportionally more and longer fixations on each of the five cued subsystems in the multiple-cueing condition when they are cued (Hypothesis 1c). Further, it was hypothesized that limiting the scope of the display that is searched by using cueing to direct attention to a region will reduce the competition for attention between simultaneously presented elements and its associated search for task-relevant information, yielding overall a lower fixation frequency and a longer average fixation duration in the animation in the cued conditions as compared to the no-cueing condition (Hypothesis 2).

In line with CLT it was expected that reducing the requirement to conduct searches to find task-relevant information will reduce extraneous cognitive load, resulting in lower mental effort while studying the animation (Hypothesis 3).

Consequently, the increase in available working memory resources can be allocated to learning (i.e., germane load). Therefore, it was expected that in accordance with the results of De Koning et al. (2007) spotlight-cueing will result in a better understanding of parts of the animation that are cued as compared to when these parts are not cued. This should be reflected in the verbal protocols that are hypothesized to contain more explanatory statements about an element when it is cued than when it is not. Hence, the number of explanatory statements in the verbal protocols were expected to be significantly higher in the multiple-cueing condition than in the single-cueing condition and the no-cueing condition, while the single-cueing condition should report a significantly higher number of explanatory statements at least on the valves system than the no-cueing condition (Hypothesis 4).

Although our main interest was on the effects of cueing on the process-related measures, we also examined its influence on learning outcomes, keeping in mind that they may be influenced by the verbal protocols in the cued retrospective reporting that preceded the measures of learning outcomes. It was expected that better understanding of cued elements, as reflected in verbal protocols, will be also reflected in the results of comprehension and transfer tests, yielding better learning outcomes on questions about cued elements on both of the latter measures. Because in the multiple-cueing condition all elements of the cardiovascular system were cued, it was expected that the multiple-cueing condition will have significantly higher learning outcomes than the single-cueing condition and the no-cueing condition (Hypothesis 5a). In addition, because in the single-cueing condition only the valves system was cued, it was expected that the single-cueing condition will have significantly higher scores on questions about the valves system than the no-cueing condition (Hypothesis 5b). Alternatively, there may be equal test performance but less mental effort involved in answering to comprehension and transfer tests because of the reduced cognitive load (Hypothesis 5c).

Method

Participants – Design

The participants were 40 psychology undergraduates (13 males and 27 females) from the Erasmus University of Rotterdam. Their mean age was 21.43 years (SD = 2.27). All were native Dutch speakers and received partial course credit or a small monetary reward for their participation. Participants had normal or corrected to normal vision. None of the participants had taken college level biology classes, but all had taken introductory courses on biology in high school that included the cardiovascular system and its basic components.

The participants were randomly assigned to one of three conditions: in the no-cueing condition (n = 13), in the single-cueing condition (n = 14), and in the multiple-cueing condition (n = 13). Three participants (one in each condition) were eliminated from further analysis due to calibration problems of the eye-tracking system, leaving 12 participants in the no-cueing group, 13 in the single-cueing group, and 12 in the multiple-cueing group.

Materials and apparatus

With the exception of the verbal protocol data, the experiment was entirely computer based allowing digital presentation of all materials and automatic recording of all data, using Macromedia Flash 7.0 (Macromedia, 2004).

Registration of eye movements

A Tobii 2150 binocular remote eye-tracker with 21 inches display was used to record eye movements. The eye-tracker operates at a sampling rate of 50Hz and has a spatial resolution of less than 0.5 degrees. The system consists of a flat panel monitor with an eye-tracking camera and infrared light emitting diodes (LEDs) mounted inside the monitor bezel. The camera's viewing angle is wide enough to allow head motion of 35 x 20 x 32 centimeters (width, height, depth) from a distance of 60 centimeters. Therefore, participants do not have to remain still during the experiment. Tobii's ClearView software was used to record eye movements, operate the calibration process, and replay the recordings of participants' eye movements. Fixations were identified as a set of gaze points that fell within a 30-pixel dispersion and together lasted for at least 100 milliseconds.

Animation

The presentation consisted of a 132 seconds animation illustrating the workings of the human cardiovascular system (Figure 1a). It depicted the dynamics of the system's five main subsystems: Circulatory system, electrical system, pulmonary circulation, systemic circulation, valves system. Although each subsystem has unique dynamic characteristics, they are dependent on each other to let the cardiovascular system function correctly. Essentially, the animation showed how the heart contracts, where blood flows in the heart, where exchange of oxygen and waste products takes place, and how the heart valves and electrical system work. The animation showed 13 cardiac cycles that each lasted for approximately 10 seconds. The animation was presented without accompanying written or verbal descriptions or labels, contained no pauses, and learners had no opportunity to control the animation.

The content of the animation was exactly the same for all three experimental conditions. The animation was divided into five episodes in which a different subsystem was cued (Figures 1b-f). The only difference was that in the single-cueing condition only the valves system was cued (Figure 1e), whereas in the multiple-cueing condition all the subsystems were cued. Each cueing encompassed a complete subsystem. This was done to increase the chance that task-relevant information was processed by directing learners' attention to specific parts of the animation without emphasizing only small fragments of the content. Cueing was done by shading all elements in the animation except the cued subsystem. This visual contrast enables the cued subsystem to become more salient because its perceptual attributes differ from those of the rest of the animation. Despite this change, all non-cued elements of the animation could still be attended to. In both cueing conditions, the cue appeared on the screen ten seconds after the start of the animation to ensure that participants would notice the visual manipulation. In the single-cueing condition the same cue remained on screen for the entire duration of the animation, but in the multiple-cueing condition cues were alternated. Each subsystem in the multiple-cueing condition was cued for 22 seconds with an inter-cueing period of three seconds in which the animation was not cued. Setting the duration for each cue in the multiple-cueing condition to 22 seconds, enabled participants to view all subsystems in at least two cardiac cycles, which allowed them to grasp at least a basic

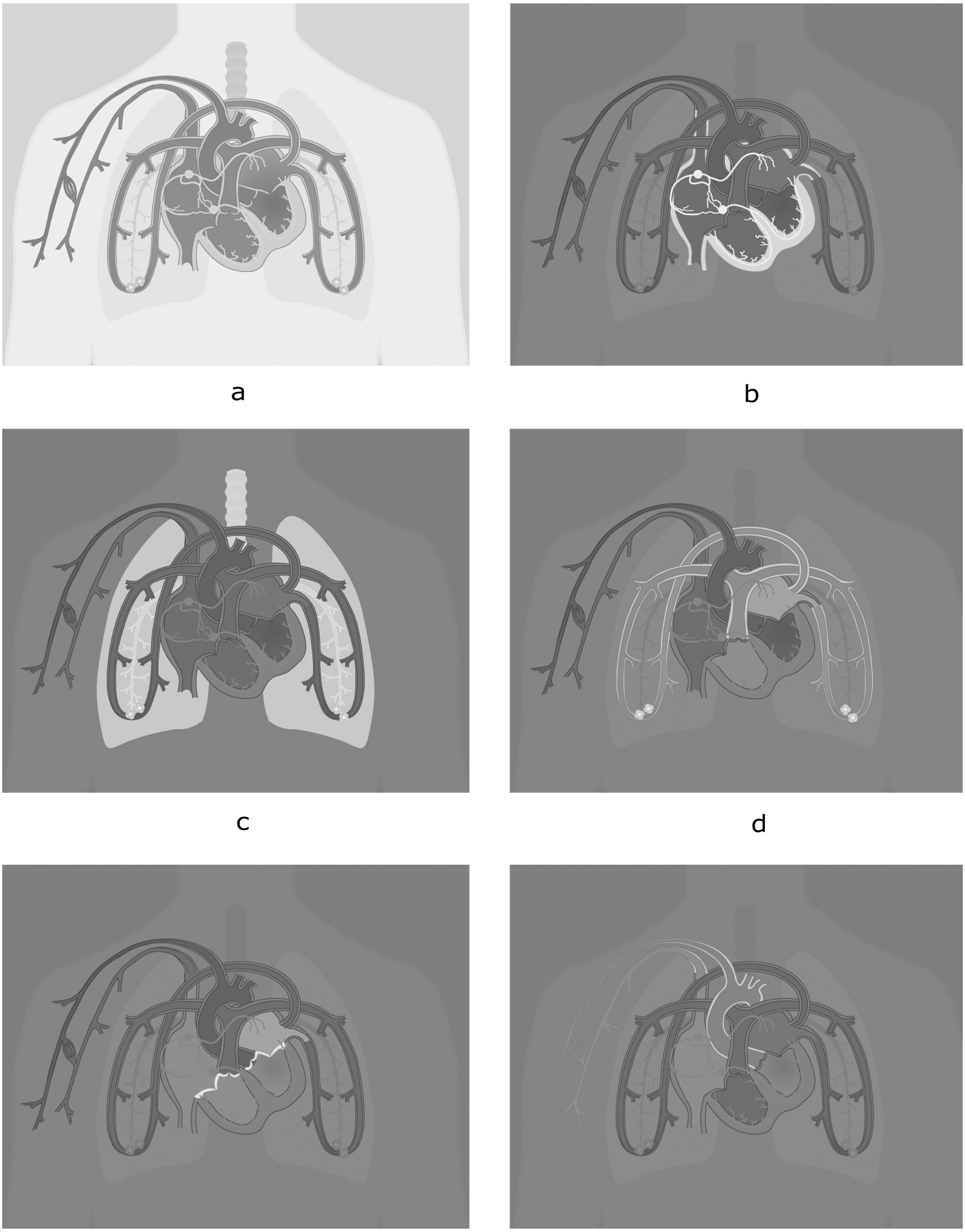


Figure 1 *Screen-examples of the non-cued animation (a) and the cued subsystems (b-f). Note: a = no-cueing, b = electrical system, c = circulatory system, d = pulmonary circulation, e = valves system, f = systemic circulation. (The screens were given in color)*

understanding of each subsystem. Cueing followed a predetermined order that was intended to follow a logical sequence in order to optimize learning (electrical system, circulatory system, pulmonary circulation, valves system, and systemic circulation).

Pre-experiment measures

Participant questionnaire

The questionnaire, which was based on Mayer and Moreno's (1998) questionnaire consisted of questions concerning the participant's gender, age, and years of university education.

Prior Knowledge questionnaire

This questionnaire, based also on Mayer and Moreno's (1998) questionnaire, consisted of five items. Participants were asked to rate their prior knowledge of the cardiovascular system with one Likert-type item on a 5-point scale ranging from 1 (very little) to 5 (very much). The other four items, in the form of a 4-item checklist, regarded their experience with biology and the cardiovascular system. For example, participants were asked whether they had followed biology classes during their secondary education or whether they knew someone in their inner circle with a heart condition. For three of the checklist items a score between 0 and 2 could be obtained, whereas for one of the checklist items a score between 0 and 3 could be obtained. Therefore, the total score for all four checklist items together ranged between 0 and 9. All five prior-knowledge items were added up to get a score, indicating overall knowledge of the cardiovascular system, ranging from 1 (no experience) to 14 (high experience). Analysis of the prior-knowledge score indicated no significant differences between the no-cueing condition ($M = 5.32$, $SD = 2.35$), the single-cueing condition ($M = 4.23$, $SD = 3.06$), and the multiple-cueing condition ($M = 4.17$, $SD = 1.34$), $F < 1$, *ns*.

Learning outcomes

To assess the participants' understanding of the cardiovascular system, a comprehension and a transfer test were used. All items covered the functional anatomy of the cardiovascular system that was presented in the animation.

Comprehension test

It consisted of 32 items and responses were given using four multiple-choice alternatives. Comparable numbers of items covered the structural and dynamic aspects of each subsystem (6 items about the electrical system: 2 static, 4 dynamic; 6 items about the circulatory system: 2 static, 4 dynamic; 5 items about the systemic circulation: 2 static, 3 dynamic; 9 items about the valves system: 3 static, 6 dynamic; 6 items about the pulmonary circulation: 2 static, 4 dynamic). An analysis of the animation in terms of the information that should be extracted or inferred from it was used to construct the test items. Hence, test items asked about all relevant elements of a subsystem and because only complete subsystems were cued the questions directly corresponded to information in a cued region. To minimize the risk thatquestions were misinterpreted or not fully understood, minimal use of terminology was made or pictures were added that referred to elements mentioned in the question. Test items were only pictorial if the questions were difficult to interpret with text alone or to clarify a concept (for sample questions, see De Koning et al., 2007).

For each correct answer to a comprehension item participants received one point, otherwise they received zero points. For all conditions, two comprehension scores were computed: An overall comprehension score (between 0 and 32) for all five subsystems and a comprehension score (between 0 and 9) for items about the cued subsystem in the single-cueing condition (i.e., valves system). Cronbach's alpha for the overall comprehension test was .76.

Transfer test

The Transfer test consisted of five open-ended questions. All transfer questions covered the workings of the subsystems shown in the animation. Each question asked participants to reason about the functioning of one of the five subsystems. These questions could only be answered correctly by making inferences about the cause-effect relations of each subsystem (i.e., cued part) and, therefore, provide a good measure of the quality of the constructed representation (Mayer, 2001). An example of a transfer question is "Explain why it is possible to divide the functioning of the electrical system into two steps."

The transfer questions were scored by counting the number of idea units per question that were included in the participant's answer. Two independent raters that were unaware of experimental condition scored the transfer items. To estimate the interrater reliability, we calculated Cohen's kappa on the pairs of scores (Cohen, 1988). The results revealed a high interrater agreement (k = .72). The maximum score was 32. As with the Comprehension test, for all conditions an overall transfer score (between 0 and 32) for all five subsystems and a transfer score (between 0 and 9) for items about the cued subsystem in the single-cueing condition (i.e., valves system) were computed. Cronbach's alpha for the overall transfer test was .61.

Verbal protocols

After viewing the animation, the recording of participants' eye movements was replayed at half the speed of the original speed and they retrospectively reported the thoughts they had while studying the animation based on their eye movements (see for a discussion on this reporting technique, Van Gog et al., 2005). Participants were allowed to pause the recording of their eye movements at any time and as often as they liked. Reducing its speed and giving participants the opportunity to control the gaze replay allowed them to verbalize in as detailed a way as possible all thoughts they had at a specific moment while studying the animation. Whenever participants stopped verbalizing their thoughts, the experimenter encouraged them after five seconds to keep on talking. The experimenter recorded the verbal protocols with an audio recorder.

Verbal protocol data were analyzed by counting how many idea units of the five subsystem(s) were incorporated in each learner's protocol (Ericsson & Simon, 1993). Each idea unit mentioned in the protocol was awarded one point, yielding a maximum score of 9 for the valves system and a total 38 for all the five subsystems. The idea units were assessed in line with Lowe's (1999) distinction between two types of statements: (a) *descriptive statements*, which contain purely descriptive terms, such as 'the heart consists of four chambers', and (b) *explanatory statements*, which express a causal mechanism, such as 'the electrical system causes the ventricles to contract'. In the valves system, a maximum number of six descriptive statements and three explanatory statements could be made. In the five subsystems, 23 descriptive statements and 15 explanatory statements could be made about the cardiovascular system. All verbal protocols were scored blind with respect to experimental condition. Two independent raters scored a randomly selected subset of approximately 25% of the verbal protocols. To estimate the interrater reliability, we calculated Cohen's kappa on the pairs of scores in this subset. The results revealed a high interrater agreement (k = .80) and therefore one rater scored the remaining protocols.

Mental effort

Participants answered a question on how much mental effort they had invested in (a) studying the animation and (b) completing the comprehension and transfer tests using a nine-point scale ranging from 1 (very, very low effort) to 9 (very, very high effort), which is known to be a reliable measure of experienced mental effort (Paas, 1992; Paas et al., 2003).

Attention

Attention was assessed by the relative number and duration of fixations on each subsystem of the animation. A method similar to the one used by Kriz and Hegarty (2007) was used. Areas of Interest (AOI) were defined for each of the five subsystems of the cardiovascular system. Furthermore, the animation was divided into five episodes that each lasted for approximately 22 seconds (i.e., approximately 2 cardiac cycles). Thus, in all three conditions there were the same five AOIs (i.e., five subsystems) in each episode. To analyze the distribution of attention over the different AOIs (i.e., subsystems) in each episode quantitatively, the number of fixations and total fixation time on each AOI in each episode were calculated and then divided by the total number of fixations or total fixated time that occurred during the episode, respectively. This resulted in two measures: the proportion of the number of fixations in each of the AOIs, and the proportion of total time fixated on each AOI.

To examine attention allocation to the cued part(s) in the multiple-cueing and the single-cueing condition, one of the five AOIs (i.e., subsystems) in each episode was selected as the cued subsystem. For the multiple-cueing condition, in each episode a different AOI was selected as the cued subsystem, that is, there were five cued AOIs (one subsystem in each episode, see Figures 1b-1f) in the animation. For instance, in the multiple-cueing condition the selected AOI in the second episode (Figure 1c) comprised the circulatory system, as this was the cued subsystem during this episode. In the single-cueing condition only the valves system was cued. Therefore, in all episodes the selected AOI was the valves system (Figure 1e). The no-cueing condition served as a baseline condition with which both cueing conditions could be compared. Therefore, in the no-cueing condition the same AOIs (i.e., subsystems) were selected as the ones in the cueing conditions to which it was compared (i.e., single-cue or multiple-cues).

Visual search

Visual search was assessed by the frequency of fixations in the animation, that is, on all AOIs (i.e., subsystems) together over all five episodes and mean fixation duration the number of fixations per participant, which were then divided by the total duration of the five episodes (i.e., 22 x 5 = 110 seconds), resulting in the number of fixations per second. Furthermore, the mean fixation duration (not just on cued subsystems) was determined, which resulted from dividing the total time fixated in a subsystem by the total time fixated in the five episodes (i.e., 22 x 5 = 110 seconds).

Procedure

Participants were tested in an individual session of approximately 45 minutes. They first filled out the participant questionnaire and the prior knowledge questionnaire and were, then, seated in front of the eye-tracking monitor. The experimenter asked the participants to take a comfortable position and not to move their head, and then started the calibration process. Subsequently, the experimenter read instructions that stated that the animation should be attended to carefully, and participants were encouraged to try to comprehend how the cardiovascular system works. Furthermore, they were told that afterwards they would be asked to verbalize their thoughts based on a record of their own eye movements.

Participants viewed the animation, depending on the experimental condition, that is, the no-cueing animation, the single-cueing animation, or the multiple-cueing animation condition. After viewing the animation, and before completing the comprehension and transfer tests, participants were given a mental effort rating scale.

Participants then completed the comprehension test. Comprehension questions could be answered by clicking on one of the four choice alternatives. Subsequently, participants were presented the transfer questions that could be answered by typing their answer in an on-screen textbox using the keyboard. All comprehension and transfer questions were individually and randomly presented on screen. Participants were able to sequentially move through the questions by clicking the ‘next’ button and were allowed to take as much time as needed to answer each question. The program did not allow them to return to previously presented questions. After each test, participants rated the mental effort they had invested in it.

Results

Table 1 shows the mean scores on the dependent measures for all three conditions. The no-cueing condition served as a baseline condition with which both cueing conditions could be compared.

Attention

To explore whether cueing had led to an overall differentiation of attention over the different subsystems in different episodes, we conducted a 3(cueing) x 5(episode) x 5(subsystem) MANOVA on the proportion of number of fixations and on the proportion of duration of time participants spent in each episode on each of the subsystems of the cardiovascular system. With respect to the distribution of attention over the five subsystems, results showed a significant main effect of subsystem, Wilks's lambda = .06, $F(8, 27) = 56.92$, $p < .05$, partial $\eta^2 = .94$, indicating that irrespective of cueing and over all episodes the proportion of number of fixations, $F(4, 136) = 70.53$, $p < .05$, partial $\eta^2 = .68$, and the proportion of total fixated time, $F(4, 136) = 64.14$, $p < .05$, partial $\eta^2 = .65$, on the subsystems was not the same.

Pairwise comparisons showed that significantly fewer fixations were made on the electrical system and that the time fixated in this subsystem was shorter as compared to all other subsystems; on the contrary, a significantly higher proportion of fixations were made on the valves system and the proportion of time fixated in this subsystem was longer than in all other subsystems ($p < .05$ in all cases). Specifically, for the electrical system, the mean proportion of fixations was .08 (*SD* = .04), and of fixated time .08 (*SD* = .04); for the circulatory system, the mean proportion of fixations was .19 (*SD* = .07), and of fixated time.19 (*SD* = .07); for the systemic circulation, the mean proportion of fixations was .18 (*SD* = .05), and of fixated time .17 (*SD* = .05); for the valves system, the mean proportion of fixations was .31 (*SD* = .07), and of fixated time .32 (*SD* = .09); for the pulmonary circulation, the mean proportion of fixations was .20 (*SD* = .04), and of fixated time .19 (*SD* = .04).

However, the interaction between episode and subsystem was not significant, indicating no overall differences in the distribution of attention over the subsystems per episode, Wilks's lambda = .46, $F < 1$, *ns*. Thus, the difference in attention distribution over the subsystems was consistent across episodes. Moreover, the interaction between cueing, episode, and subsystem was also not significant, Wilks's lambda = .68, $F < 1$, *ns*. Thus, cueing did not influence the distribution of attention over the subsystems and over episodes. Together, these results suggest that, although different subsystems received different amounts of attention, attention to the subsystems was not determined by cueing.

Although the effect of cueing was not strong enough to find differences in the general distribution of attention between the three conditions, more specific effects of cueing on the distribution of attention to specific subsystems are likely to manifest itself in the two cueing conditions as compared to the no-cueing condition. That is, we had specific hypotheses that

Table 1 *Means and standard deviations of the dependent measures as a function of cueing*

	No Cue		Single Cue		Multiple Cues	
	M	*SD*	*M*	*SD*	*M*	*SD*
Attention: Overall proportion of number of fixations (averaged over all episodes)						
Electrical system	.11	.04	.06	.03	.08	.03
Circulatory system	.22	.08	.22	.05	.15	.04
Systemic circulation	.18	05	.16	.04	.18	.04
Valves system	.25	.07	.32	.07	.35	.07
Pulmonary circulation	.19	.05	.19	.03	.20	.05
Attention: Overall proportion of duration of fixations (averaged over all episodes)						
Electrical system	.11	.04	.06	.03	.07	.03
Circulatory system	.22	.08	.23	.06	.14	.05
Systemic circulation	.18	.05	.15	.05	.16	.04
Valves system	.25	.06	.33	.09	.37	.10
Pulmonary circulation	.20	.05	.18	.03	.20	.05
Visual search						
Average fixation duration (ms)	229.12	61.45	239.68	56.47	224.85	78.05
Fixation frequency	2.83	.53	3.10	.39	2.55	.77
Mental effort animation (range 1-9)	5.58	1.38	5.38	1.94	5.58	1.62
Cognitive processes: Verbal protocol – statements all subsystems						
Word count	454.00	115.95	515.15	120.19	512.42	117.18
Cognitive processes: Verbal protocol - statements overall						
Descriptive (range 0-23)	4.25	2.34	4.62	1.76	5.92	2.07
Explanatory (range 0-15)	1.92	1.44	2.31	1.38	1.33	1.50
Cognitive processes: Verbal protocol – statements valves system						
Total (range 0-9)	.25*	.87	1.46*	1.56	1.83*	1.53
Descriptive (range 0-6)	.17	.58	1.00	1.15	1.25	.97
Explanatory (range 0-3)	.08	.29	.46	.66	.58	.79
Learning performance						
Comprehension (range 0-32)	17.17	4.76	17.69	5.36	18.33	5.84
Transfer (range 0-32)	6.42	4.38	8.31	4.94	7.92	4.32
Comprehension valves system (range 0-9)	4.92	1.78	5.77	2.28	6.25	1.42
Transfer valves system (range 0-9)	1.00	.74	1.46	.78	1.25	.97
Mental effort						
Comprehension (range 1-9)	7.42	1.08	7.08	1.12	6.50	1.24
Transfer (range 1-9)	6.25	1.42	7.23	1.30	6.17	1.75

* $p < .05$

cueing would influence the proportion of number of fixations and the proportion of time fixated on the cued subsystem(s) in the single-cueing and the multiple-cueing condition as compared to the no-cueing condition. It was expected that, compared to the no-cueing condition, there would be a higher proportion of number of fixations and a higher proportion of fixated time on the valves system in the single-cueing condition (cf. Hypothesis 1b) and a higher proportion of number of fixations and a higher proportion of fixated time on the five cued subsystems in the multiple-cueing condition when they are cued (cf. Hypothesis 1c), compared to the no-cueing condition. Because different subsystems were cued in the five episodes in the single-cueing and the multiple-cueing condition, the fixation data of the three conditions could not be compared in a single MANOVA, but required separate comparisons of two conditions (single-cueing vs. no-cueing and multiple-cueing vs. no-cueing). In what follows, these comparisons will be presented.

Single-cueing condition

To investigate attention allocation to the cued part (i.e., the valves system) in the single-cueing condition, a repeated measures MANOVA on the proportion of number of fixations and the proportion of time fixated on the cued subsystem (i.e., valves system) with cueing (i.e., single-cueing vs. no-cueing condition) as the between subjects factor and the five episodes as the within subjects factor was conducted. This analysis allowed us to examine whether cueing directed attention to the valves system, and could inform us whether cueing guided attention to the cued subsystem at different episodes in the animation.

The results showed (see Figure 2) a significant main effect of cueing, Wilks's lambda = .76, $F(2, 22) = 3.46$, $p < .05$, partial $\eta^2 = .24$, indicating that in the single-cueing condition a higher proportion of fixations were made on the cued subsystem ($M = .32$, $SD = .07$) than in the no-cueing condition ($M = .26$, $SD = .06$), $F(1, 23) = 5.68$, $p < .05$, Cohen's $d = .96$, and that the proportion of total fixated time in this AOI was longer ($M = .33$, $SD = .08$) than in the no-cueing condition ($M = .26$, $SD = .05$), $F(1, 23) = 7.11$, $p < .05$, Cohen's $d = 1.08$. The main effect of episode was not significant, Wilks's lambda = .67, $F < 1$, *ns*. The interaction was significant, Wilks's lambda = .34, $F(8, 16) = 3.94$, $p < .05$, partial $\eta^2 = .66$, indicating that over episodes cueing differentially affected the attention to the valves system.

Post hoc analyses showed that only in the first episode the proportion of fixations, $F(1, 24) = 38.63$, $p < .05$, Cohen's $d = .39$, and the proportion of total fixated time, $F(1, 24) = 41.25$, $p < .05$, Cohen's $d = .44$, were higher in the single-cueing condition ($M = .44$, $SD = .10$, and $M = .46$, $SD = .12$, respectively) than in the no-cueing condition ($M = .21$, $SD = .09$, and $M = .22$, $SD = .07$, respectively). Therefore, although cueing effectively guided attention to the cued part its influence was restricted to the first episode.

Multiple-cueing condition

To investigate attention allocation to the cued part in the multiple-cueing condition, a repeated measures MANOVA for the proportion of number of fixations and of proportion of time fixated on the cued subsystems with cueing (i.e., multiple-cueing vs. no cueing) as the between subjects factor and the five episodes as the within subjects factor was conducted.

The results revealed (see Figure 3) a significant main effect of cueing, Wilks's lambda = .71, $F(2, 21) = 4.30$, $p < .05$, partial $\eta^2 = .29$, indicating a higher proportion of fixations, $F(1, 22) = 8.58$, $p < .05$, Cohen's $d = .87$, and a higher proportion of total fixated time, $F(1, 22) = 8.93$, $p < .05$, Cohen's $d = .87$ in the multiple-cueing condition (mean proportion of

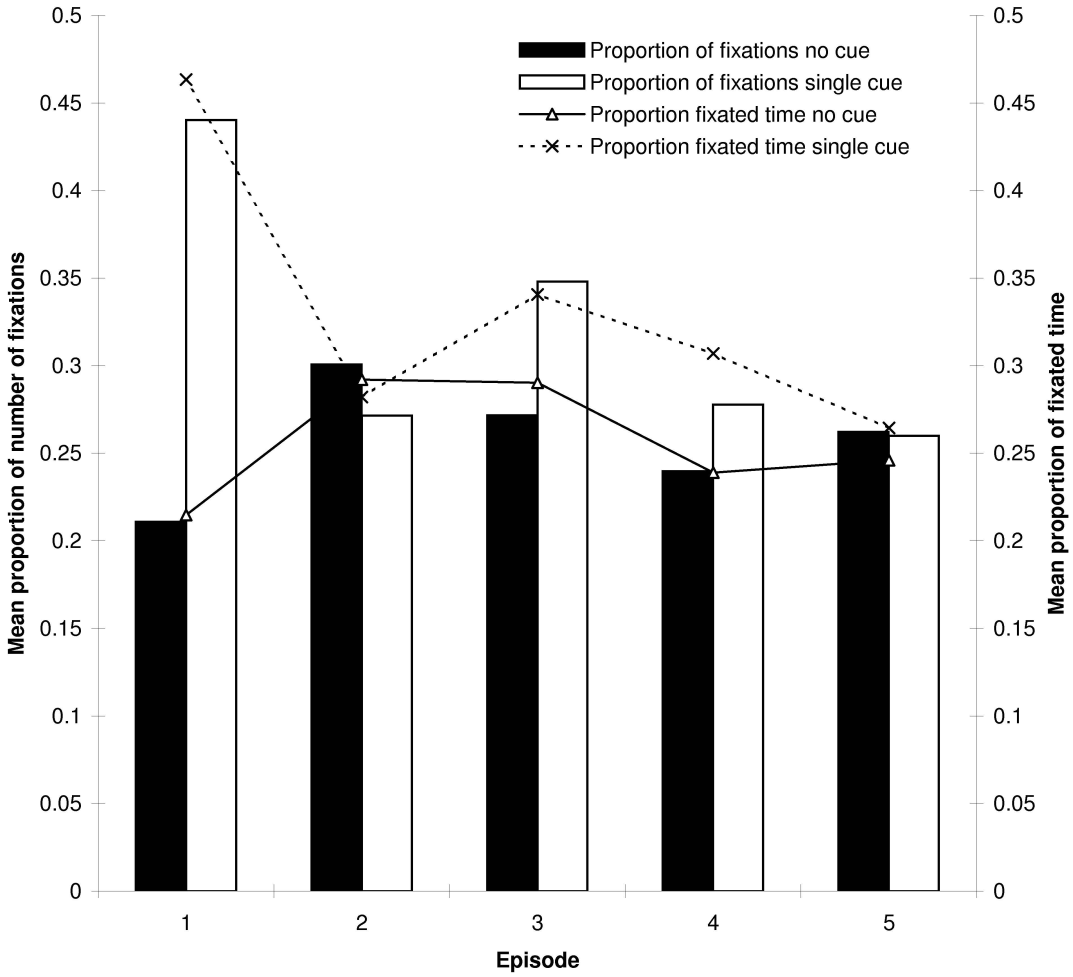


Figure 2 *Mean proportion of number and duration of fixations on the valves system over time for the no-cueing and the single-cueing condition*

fixations .25, $SD = .06$, and mean proportion of fixated time .24, $SD = .05$), compared to the no-cueing condition (mean proportion of fixations .19, $SD = .04$, and mean proportion of fixated time .19, $SD = .04$). Hence, as in the single-cueing condition, in the multiple-cueing condition attention was effectively guided to the cued parts.

In addition, a main effect of episode was found, Wilks's lambda = .22, $F(8, 15) = 6.65$, $p < .05$, partial $\eta^2 = .78$, indicating that both the proportion of fixations, $F(4, 88) = 10.28$, $p < .05$, partial $\eta^2 = .32$, and proportion of fixated time, $F(4, 88) = 9.41$, $p < .05$, partial $\eta^2 = .30$ differed across episodes. This suggests that irrespective of the presence of cueing, the subsystems that were sequentially cued in the multiple-cueing condition were not equally attended to. Most attention was allocated to the valves system (mean proportion of fixations

.31, *SD* = .14, and mean proportion of fixated time .32, *SD* = .16) followed by the systemic circulation (mean proportion of fixations .24, *SD* = .11, and mean proportion of fixated time .23, *SD* = .11); the pulmonary circulation (mean proportion of fixations .22, *SD* = .09, and mean proportion of fixated time .22, *SD* = .10); the circulatory system (mean proportion of fixations .20, *SD* = .09, and mean proportion of fixated time .19, *SD* = .09); and the electrical system (mean proportion of fixations .13, *SD* = .08, and mean proportion of fixated time .13, *SD* = .09). The interaction between cueing and episode was not significant, Wilks's lambda = .74, $F < 1$, *ns*, indicating that cueing did not differentially influence the attention to the five subsystems. Thus, we found direct evidence that cueing increases attention as compared to no-cueing, but attention was not necessarily driven to the cued parts.

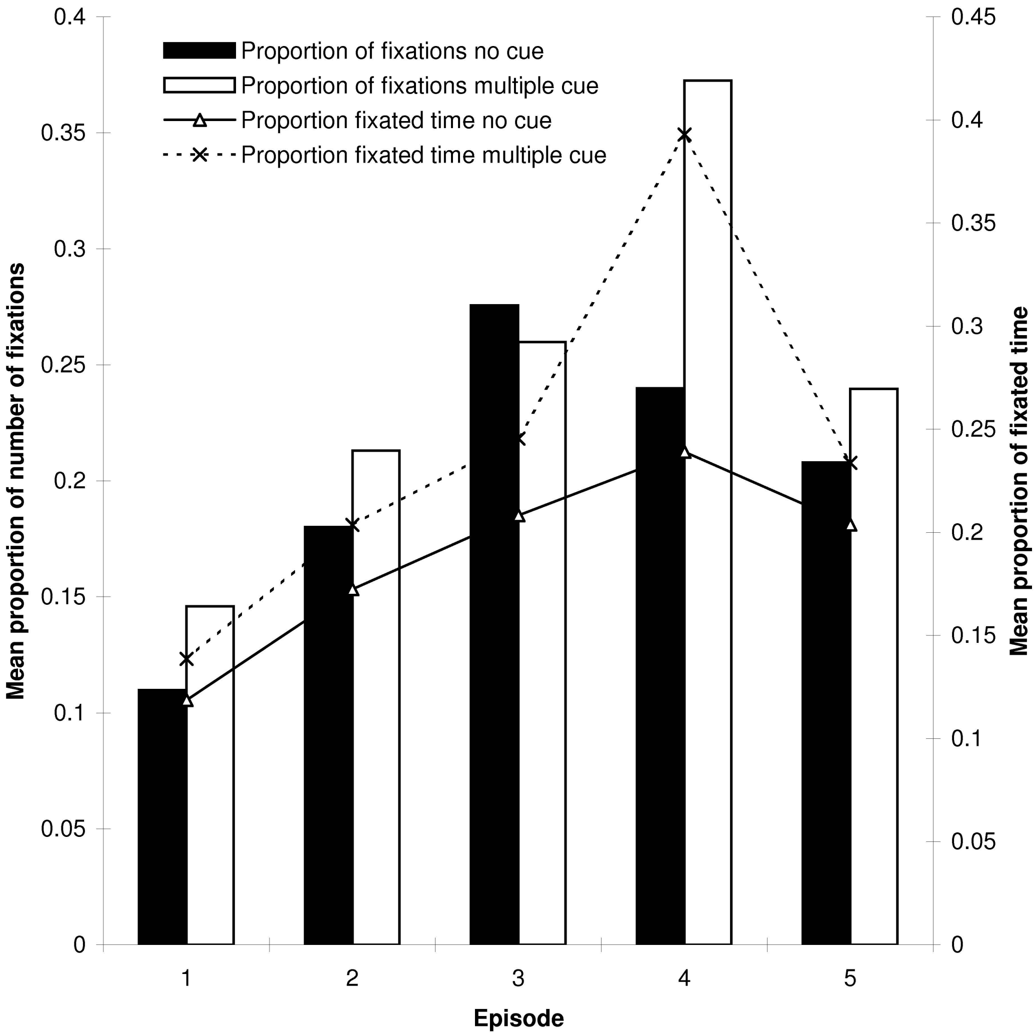


Figure 3 *Mean proportion of number and duration of fixations on cued subsystems for the no-cueing and multiple-cueing condition*

Visual search and mental effort

To examine whether cueing reduces visual search, a MANOVA was conducted with cueing (i.e., single-cueing vs. multiple-cueing vs. no-cueing) as the between subjects factor and mean fixation duration and fixation frequency as dependent variables. No effect of cueing was found between any of the three conditions on fixation frequency and mean fixation duration, which are indicative of the amount of visual search, Wilks's lambda = .81, $F(4, 66)=1.84$, *ns*. The ANOVA with the three conditions as between subjects factor and the mental effort rating regarding the studying of the animation as dependent variable also revealed no significant differences between the cued conditions and the non-cued condition, $F < 1$, *ns*.

Cognitive processes

The cued retrospective verbal protocols were used to uncover what cognitive processes occurred during learning from cued and non-cued animation. The verbal protocols did not significantly differ between the three conditions in the number of words expressed, $F(2, 36) = 1.05$, *ns*. The option to stop the replay of eye movements during the verbalization process was used once by only a few participants. This had little influence on other measures and was therefore not further analyzed.

With regard to the cognitive processes that presumably occurred during studying the animation, the 3 (cueing) x 2 (type of statement: descriptive vs. explanatory) MANOVA revealed that the number of explanatory and descriptive statements in the participants' protocols about the cardiovascular system did not significantly differ between the three conditions, Wilks's lambda = *.77*, $F < 1$, *ns*. Further, we were interested in the total number of statements made about the valves system, as this was the cued subsystem in the single-cueing condition. An ANOVA on the total number of statements made about the valves system with cueing as the between subjects factor showed a significant main effect of cueing, $F(2, 34) = 4.45$, $p < .05$, partial $\eta^2 = .21$.

Post hoc analyses revealed that participants in the single-cueing condition, $t(23) = 2.42$, $p < .05$, Cohen's $d = .96$, and the multiple-cueing condition, $t(22) = 3.12$, $p < .05$, Cohen's $d = 1.27$, reported more statements on the functioning of the valves system ($M = 1.46$, $SD = 1.56$ and $M = 1.83$, $SD = 1.53$, respectively) than participants in the no-cueing condition ($M = .25$, $SD = .83$). However, looking at descriptive and explanatory statements separately, the respective 3(cueing) x 2(type of statement: descriptive vs. explanatory) MANOVA revealed no significant multivariate effects of cueing, Wilks's lambda = *.79*, $F < 1$, *ns*.

Learning outcomes

A 3(cueing) x 2(learning outcome) MANOVA on the total comprehension and transfer scores revealed that viewing an animation with a single cue or with multiple visual cues did not lead to better comprehension and transfer performance than viewing the animation without visual cues, Wilks's lambda =.95, $F < 1$, *ns*. The MANOVA comparing the three conditions on only the comprehension and transfer scores about the valves system, revealed no main effect of cueing, Wilks's lambda = .88, $F(4, 66) = 1.08$, *ns*.

A MANOVA with cueing (i.e., single-cueing vs. multiple-cueing vs. no-cueing) as the between subjects factor and mental effort scores after the Comprehension and Transfer test as dependent variables revealed no significant differences between the three conditions, Wilks's lambda = .69, $F < 1$, *ns*. Therefore, the results on learning outcomes showed that studying an animation with spotlight-cues did not lead to better comprehension and transfer performance, nor to a differentiation of mental effort.

Discussion

The present study examined how visual spotlight-cues influence attention allocation and cognitive processing when learning from a complex instructional animation. As expected, learners looked more often and for longer periods of time at cued than at non-cued content (Hypothesis 1b and 1c). This difference in fixation patterns between the cued and non-cued conditions is taken as evidence that cueing guides learners' attention to specific regions in an instructional animation. The fixation pattern in the single-cueing condition suggests that the attention guidance provided by a single spotlight-cue focuses the learners' attention on the cued part for only a short period of time after its onset. This may be an effective feature of cueing for tasks that require learners to shift attention continuously, such as when focusing attention successively on the individual steps of a procedural task. However, contrary to our expectations, cueing did not lead to a general shift of attention distribution over the subsystems over time (Hypothesis 1a). Thus, the effect of attention guidance to specific elements in the animation was restricted to increasing attention for the parts when they are cued and was not at the cost of attending to other subsystems of the cardiovascular system. These findings suggest that spotlight-cues only determine when or in what order certain elements of the animation are attended to, which can be very helpful in assisting learners to decide what elements to attend to and at what time (Schnotz & Lowe, 2008).

The hypotheses that spotlight-cues would reduce the amount of visual search (Hypothesis 2) and extraneous cognitive load (Hypothesis 3) were not confirmed. A possible explanation for this might be that this type of cueing only limited the size of the total display area attended to without providing guidance for processing the information within this region, leaving low-knowledge learners with a visual search situation (and its associated requirements) analogous to processing an non-cued animation. Whether emphasizing the causal relations within a cued part of an animation will reduce processing demands remains to be addressed.

With respect to cognitive processes, it was found that studying an animation with a single spotlight-cue resulted in more statements about the cued subsystem in the verbal protocol data than studying an animation without cues. This finding suggests that with a visual cue appropriate cognitive processes can be stimulated. However, the hypothesis that focusing attention in a complex animation using one or multiple spotlight-cues would elicit more explanatory statements about the cued subsystem(s) was not confirmed (Hypothesis 4). In all conditions learners generated a rather low number of explanatory statements (approximately two out of fifteen). Further, we did not replicate the results of De Koning et al. (2007) with respect to the learning outcome measures (Hypotheses 5a and 5b) and we did not find support for the hypothesis that answering to comprehension and transfer tests requires less mental effort (Hypothesis 5c), which is not surprising given the small cueing-effect in the verbal report data and the modest statistical power of the present study. Additionally, the positioning of the cued retrospective protocols before the learning test may have provided learners the opportunity to employ activities that produce a greater cognitive engagement (e.g., giving explanations of their thought processes) thus overshadowing any effects of cueing. So, it seems that the effect of cueing on conceptual understanding is influenced by how the animation with spotlight-cues is embedded in the instructional procedure (see Ayres & Paas, 2007a). The results suggest that using spotlight-cues to have learners look at the correct region in an animation does not necessarily stimulate them to infer crucial relations between different components of the cardiovascular system (see Kriz & Hegarty, 2007). It seems that it is difficult for low-knowledge learners who process perceptually salient information to (re)direct the focus of attention to a specific region in a complex animation and be able to develop an accurate conceptual understanding of the content. Together with the results of Kriz and Hegarty (2007) the present findings suggest that the perceptual processes of selecting and extracting information from a complex instructional animation should be considered separately from the conceptual processes of understanding what is depicted in a visualization. Nevertheless, for different learning materials, such as problem-solving tasks, there is evidence that visual cues can improve conceptual understanding (Grant & Spivey, 2003). It would be interesting to analyze the types, goals, and functions of cueing in these tasks and compare them to those in animations in trying to explain the discrepant findings and improve the cueing strategy in animations.

Some critical observations can be made regarding this study. First, this study examined the effectiveness of spotlight-cueing, which is only one type of cueing that may or may not generalize to other types of cueing (e.g., using arrows; see also Boucheix & Lowe, in press). Nevertheless, on the basis of similar studies using different types of cueing we are confident that some of our findings can be generalized more broadly. For example, using respectively spotlight-cueing and arrow-cues both the present study and the Kriz and Hegarty (2007) study found that visual cues mainly influence perceptual processing rather than cognitive processing. Second, presenting the animation for two minutes may have been a too short duration to draw generalizable conclusions, at least for longer educational tasks. It is therefore desirable to replicate the present results in learning environments that engage learners for more extended periods of time. Third, a replication with a larger sample size is desirable, because these small sample sizes do not warrant any definite claims due to modest statistical power.

In sum, the present study demonstrates that the use of process-related measures can produce more specific insights on the perceptual and cognitive processes that take place in learning from an instructional animation. A practical implication is that cues can guide attention to regions containing task-relevant information but not necessarily to the information itself and hence does not guarantee further beneficial processing. Visual cueing may or may not be an effective technique to fulfill the learning goal depending on whether the specific goals of instruction involve orienting to specific locations, requires learners to comprehend the information depicted in a complex visualization, or a combination of both. Therefore, spotlight-cueing can effectively guide attention in an animation, but other factors are also important in determining the effectiveness of attention-directing cues on learning.

Chapter

5

Improved effectiveness of cueing by self-explanations when learning from a complex animation[4]

[4] This chapter is submitted for publication as: De Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2009). *Improved effectiveness of cueing by self-explanations when learning from a complex animation.* Manuscript submitted for publication.

Abstract

A major problem in learning from instructional animations is that the complex perceptual and cognitive processing exceeds the learner's limited processing capacities. Although attention cueing might help learners in focusing on essential parts of an animation, previous studies have shown that it does not necessarily improve learning performance. This study investigated whether generating self-explanations while studying a cued or an uncued animation might engage learners in cognitive activities necessary for learning. It was hypothesized that learning from a cued animation that reduces working memory load associated with searching for specific elements might be improved by generating self-explanations, whereas self-explaining with an uncued animation would have no positive effect on learning. The results confirmed the hypothesized interaction between cueing and self-explaining. They suggest that self-explanation enhances learning if visual cues are used to structure and highlight the essential parts of an animation.

Introduction

Instructional animations are increasingly used in computer-based learning environments because they extend the possibilities of static visualizations by explicitly depicting dynamic characteristics (i.e., motion, trajectory, and timing) of events and processes. Intuitively, animations should therefore be particularly well suited to enhance the learners' understanding of phenomena in which motion and change-related information is essential for building an accurate mental representation. A recent meta-analysis by Höffler and Leutner (2007) supports this notion and provides evidence that under some conditions animations may be superior to equivalent static graphics.

However, most reviews and empirical studies have failed to establish a clear advantage of animations over their static counterparts (e.g., Hegarty, Kriz, & Cate, 2003; Mayer, Hegarty, Mayer, & Campbell, 2005; Tversky, Morrison, & Bétrancourt, 2002). Several recent studies have suggested a number of reasons for the ineffectiveness of animations. For example, Hasler, Kersten, and Sweller (2007) and Ainsworth and VanLabeke (2004) have argued that because animations are transient, learners may miss or only partially process essential information and therefore fail to construct an adequate mental representation. In addition, Lowe (1999) has suggested that animations increase the demands on visual attention, as perceptually salient elements may attract the learners' attention away from more subtle but thematically relevant elements of animations. Another suggested hindrance in learning from animations concerns the fact that they seem to encourage passive rather than active learning (Hegarty et al., 2003). Whereas understanding the operation of a complex dynamic system from static graphics requires learners to infer the system's temporal changes through a process of internal animation, understanding the operation of a complex dynamic system from instructional animations requires learners to perceive the temporal changes by merely looking at an external display without necessarily having to engage in learning-related activities. Therefore, learners may be much less cognitively engaged in learning from animations than from static graphics. In the present study, we examined the instructional effectiveness of focusing learners' attention on essential aspects of an animation when they are encouraged to actively process the presented information by generating self-explanations.

Instructional animations and learning

Understanding a complex dynamic system, such as a mechanical or biological system, through an animation requires learners to construct an internal mental representation that exactly represents the objects and their configuration, the behavior of objects (i.e., movements), and the causal relations of events in the systems' behavior (Hegarty et al., 2003). A key aspect of the comprehension process involves accurately extracting the crucial information from the visual display, which may subsequently serve as input for further processing. However, there is currently no comprehensive theory that explains all the perceptual and cognitive factors involved in learning from animations. Several theoretical models may be used. For example, Hegarty's (2005) general model of comprehension of visual displays explicitly identifies perceptual characteristics of the elements in the visual display as important features that may affect what information is extracted. The model proposes that the quality of the constructed mental representation is influenced by the perceptual characteristics of the objects in the visualization and the knowledge-driven processes of the learner.

Besides theoretical models that mainly emphasize perceptual aspects, several more cognitively oriented theoretical models suggest that another aspect that may significantly affect the degree to which animations are processed satisfactorily is the limited capacity of the learners' working memory resources. For example, according to cognitive load theory (CLT; Paas, Renkl, Sweller, 2003) and Mayer's cognitive theory of multimedia learning (Mayer, 2001) animations may place high cognitive load on the learners' cognitive resources associated with specific aspects of complex animations such as the temporally distributed nature and the high information load of the presentation. According to such an account, when animations fail to improve learning it is likely to be due in part to the high ineffective or extraneous load they produce (Ayres & Paas, 2007).

In a visual display, dynamic information such as movements and sudden appearances of an object effectively attracts human visual attention (Hillstrom & Chai, 2006). Therefore, an animation showing a large number of elements that may differ substantially with respect to their perceptual characteristics (i.e., color, form, orientation), might contain several elements that simultaneously compete for attention, be it relevant for understanding the content or not. Especially novices can easily be overwhelmed by the high information load as they do not know which elements should be attended to. For example, it has been found that brightly colored elements that contrast greatly with surrounding elements may easily distract learners' attention away from essential information, forcing them to conduct searches to find relevant information (Lowe, 2003). The process of locating task-relevant information might have detrimental effects on the learners' exploration of a complex animation because unnecessary visual searches require a large amount of working memory resources and therefore can be interpreted as creating ineffective cognitive load (e.g., Ayres & Paas, 2007). Thus, processing complex animations with many (irrelevant) salient details might require so much cognitive resources that little remains for processing the actual subject-matter. Consequently, learners may fail to extract essential information from the display that is required for building a satisfactory mental representation of the content depicted in the animation. Furthermore, superficial processing of an animation may occur because learners might study animations in a passive viewing mode, that is, they perceive the dynamic information from the external display without engaging in relevant cognitive activities (Hegarty et al., 2003; Schnotz & Rasch, 2005). This may mislead learners into believing that they have understood the content correctly (Rozenblit & Keil, 2002). Awan and Stevens (2005) suggest that a higher confidence level for learners studying animations may lead to the (inaccurate) perception that animations are easier to process, and consequently, results in a lower investment of mental effort in activities relevant for learning that hence may hinder the construction of an elaborated mental representation.

Supporting learners' visual processing

Several researchers have argued that effective learning from animations may be enhanced when the visual search associated with splitting one's attention between and/or within representations is reduced by visual cues that direct learners' attention to essential parts of an animation (Bétrancourt, 2005; Mayer & Moreno, 2003; Lowe, 1999). Novices in particular, who rely heavily on bottom-up processing and engage in high visual search at the cost of cognitive capacity, are likely to benefit from attention guidance provided by a cue in what information to select and how to organize it. By reducing visual search processes and the ineffective cognitive load associated with it, mental activities that might overload working memory resources are reduced and cognitive resources that may be used for productive learning activities are freed. Thereby, the learners' attentional focus is directed to relevant parts of an animation, which provides an opportunity to concentrate on understanding the content and the underlying principles.

Using eye-tracking to examine attention allocation in learning from cued and uncued animations Kriz and Hegarty (2007) and De Koning, Tabbers, Rikers and Paas (in press) have demonstrated that the use of attention-directing cues (i.e., arrow-cues and spotlight-cues) is an effective strategy to (re)direct the learners' focus of attention towards specific elements in an animation. Therefore, it might be argued that focusing attention on different elements at different moments in time may provide an organizational structure that can be used to gradually build up an understanding of a complex dynamic system. However, using cues to emphasize which elements in an instructional animation are crucial to understanding does not ensure that the conceptual relations between the various elements are in fact detected (De Koning et al., in press; Kriz & Hegarty, 2007; Schneider & Boucheix, 2008; but see De Koning, Tabbers, Rikers, & Paas, 2007). Therefore, attention-directing cues seem *necessary* to help learners in selecting and extracting essential parts of an animation, but such cues are not *sufficient* to stimulate learners to engage in the active knowledge construction necessary for learning.

Increasing learners' cognitive engagement

Hence, for learning to occur in complex animations with cues, stimulating learners to engage in active processing of an animation will increase the probability that they understand the presented information (Mayer, 2001). Consequently, instructional techniques should be used that help learners to invest working memory resources in activities relevant for learning. A substantial number of studies have demonstrated that learners develop a deeper understanding of instructional materials if they generate explanations to themselves during learning (Aleven & Koedinger, 2002; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, de Leeuw, Chiu, & LaVancher, 1994; Renkl, Stark, Gruber, & Mandl, 1998). Several reasons have been proposed as to why engaging in active cognitive processing of learning material by generating self-explanations is an effective approach to improve learners' understanding. For example, self-explanations enable learners to integrate the new knowledge with prior knowledge and/or with information within the learning material. In addition, self-explaining forces learners to explicate their understanding, and to generate inferences to fill in missing information, which might help them to monitor and revise their knowledge base (Renkl & Atkinson, 2002). These key cognitive mechanisms may induce learners to construct a more integrated representation, yielding higher transfer of learning (Chi et al., 1994). According to Renkl and Atkinson (2003), the self-explanation activities may be considered effective or germane cognitive load because self-explaining increases cognitive load but directly contributes to the construction of a mental representation.

Recently, several studies have examined whether the format of the instructional materials influences the effectiveness of self-explanations. Of most relevance to the present study are studies on self-explaining when learning from diagrams. According to Cox (1999) and Brna, Cox, and Good (2001) diagrams facilitate self-explaining because compared to text, they require less mental computation and provide explicit feedback to which the learners can compare their explanations. Comparing learners who self-explained with either text or diagrams about the cardiovascular system, Ainsworth and Loizou (2003) provided evidence for this suggestion. However, Butcher (2006) argues that not all diagrams are effective for providing meaningful self-explanations. She demonstrated that diagrams that provide attentional guidance to its essential parts and relations rather than diagrams in which these elements are less conspicuous are most effective for eliciting meaningful self-explanations and hence promoting conceptual understanding. A potential reason for this is that although generating self-explanations is a deeply constructive activity, it requires considerable cognitive capacity (Renkl, 2005; Roy & Chi, 2005). This suggests that the effectiveness of self-explanations is influenced by the amount of the learners' available working memory resources, and does not contribute to learning if the total cognitive capacity is exceeded.

As the majority of studies have examined the effects of self-explaining in static visualizations and/or text, the present study is, to our knowledge, the first study investigating the effects of self-explaining with an instructional animation. For learning from an animation, self-explanations are believed to improve conceptual understanding as it encourages learners to activate their acquired knowledge of the depicted system and enables them to verify their knowledge against the actual processes that are explicitly displayed in the animation. Butcher's (2006) finding that attentional guidance to relevant information in a visualization enhances self-explaining suggests that self-explaining might especially be an effective cognitive activity to improve the learning performance from a cued animation. That is, attention-directing cues that guide the learners' attention to essential parts of an animation facilitate the selection and extraction of important elements and, hence create a situation in which the engagement in learning-related activities (i.e., self-explaining) is more likely to occur effectively. In contrast, engaging in the cognitively demanding, but constructive activity of providing self-explanations while studying an uncued animation is less likely to improve learning performance due to the high information load in the absence of attentional guidance. Thus, animations that reduce cognitive activities that might place excessive demands on working memory (i.e., searching for relevant parts) and use techniques such as self-explanation for increasing the cognitive engagement with genuine learning activities may provide a highly effective instructional combination for improving learning (see Paas et al., 2003).

In this study, we presented learners a cued or an uncued animation about the cardiovascular system and encouraged them to generate self-explanations while viewing the animation. In the cued conditions, spotlight-cues were used to emphasize the main subsystems of the cardiovascular system. Because cues seem very effective at capturing attention (Kriz & Hegarty, 2007), the spotlight-cues were used to focus learners' attention on relevant parts of the animation and to minimize processing of irrelevant aspects. Consequently, the high visual search and load associated with the selection of essential information are therefore likely to be reduced, thereby increasing working memory resources available for generating meaningful self-explanations (Renkl & Atkinson, 2003). Alternatively, it may be argued that consecutively cueing essential parts of the system depicted in the animation may provide a structured sequence of meaningful functional elements that learners can use to organize their self-explanation activities. In this way, the amount of information that needs to be processed in working memory at one time is reduced, which provides an opportunity to effectively engage in the process of generating meaningful self-explanations.

Because self-explaining is carried out in a continuous, ongoing and piecemeal fashion it gives rise to multiple opportunities to incrementally build up and revise one's internal mental representation that, ultimately, may lead to a fully integrated mental representation of the depicted content. The active processing of the presented information is thus a crucial factor for learning, especially if the purpose is for learners to generate deeper understanding of the material (also see Ainsworth & Loizou, 2003; Butcher, 2006; Renkl, 2005). Therefore, it was expected that the effect of self-explaining with spotlight-cues would be reflected in all levels of understanding, but is likely to be more pronounced on measures of deep learning. Consequently, we hypothesized an interaction between cueing and self-explaining, indicating that learners studying a cued animation would benefit from self-explanations yielding higher performance on inference and transfer tests and to a lesser degree on a retention test[1], whereas learners studying an uncued animation would not be able to profit from self-explanations and thus would not enhance their performance on these learning tests. In addition to the performance measures, we also examined the self-explanation protocols to see whether self-explaining with a cued or an uncued animation elicited qualitatively different self-explanations. It was hypothesized that attention-directing cues would promote the generation of meaningful self-explanations due to less visual search and an increase in working memory resources, indicating more meaningful self-explanations in the self-explanation protocols when self-explaining with a cued animation than when self-explaining with an uncued animation.

[1] From this point forward, the comprehension test as used in the previous Chapters will be referred to as the retention test

Method

Participants and design

The experiment conformed to a factorial design with the factors visual cueing (yes, no) and self-explaining (yes, no). The participants were 90 high school students (63 males and 27 females) with an age range between 13 and 15 years. Originally, 95 students participated, but due to loss of data five students were eliminated from further analyses. Participants were randomly assigned to one of four conditions, which resulted in 21 participants in the condition with visual cueing and self-explaining, 25 in the condition with visual cueing and without self-explaining, 21 in the condition without visual cueing and with self-explaining, and 23 in the condition without visual cueing and without self-explaining. All participants were native Dutch speakers and participated voluntarily. Participants had normal or corrected to normal vision and were unaware as to the exact purpose of the study. The experiment was part of an introductory biology course on the functioning of the cardiovascular system. Although the students had been introduced to the different structural components of the cardiovascular system, according to the teacher they were ignorant of the exact functioning of the system's dynamics (e.g., timing) at the time of the experiment. Before this course, they had not been taught any course on the workings of the heart and the blood flow, so the subject matter was new for them.

Materials

The computer-based learning environment consisted of a demographic questionnaire, an animation, a static diagram, a mental effort rating scale, a retention test, an inference test, and a transfer test. It was developed with Macromedia Flash 7.0 (Macromedia, 2004). The materials were electronically presented on a 17" LCD color computer screen with a resolution of 1024 x 768 pixels. With the exception of the self-explanation data, all data were automatically recorded.

Demographic questionnaire

The experiment started with a questionnaire, which was based on Mayer and Moreno's (1998) questionnaire, in which participants were asked to indicate their gender, age, years of high school education, and experience with the cardiovascular system. Participants rated their experience with the cardiovascular system on a 5-point scale, ranging from very little (1) to very much (5). The mean experience scores, i.e. 2.76 for the cued self-explaining condition, 2.32 for the uncued self-explaining condition, 2.35 for the no-explaining with cues condition, and 2.14 for the no-explaining without cues condition did not differ, F (4, 97) = 1.14, MSE = 0.85, p > .05.

Static diagram

In all conditions, participants studied a labeled static diagram which showed a colored picture of the cardiovascular system in a relaxing state and included labels naming the parts of the system (see Figure 1). For the labels, general terms (e.g., valves) instead of the specific terminology (e.g., tricuspid valve) were chosen to represent the structures of the cardiovascular system, because naming the system's structures in general terms avoids confusing different terms for the same concept.

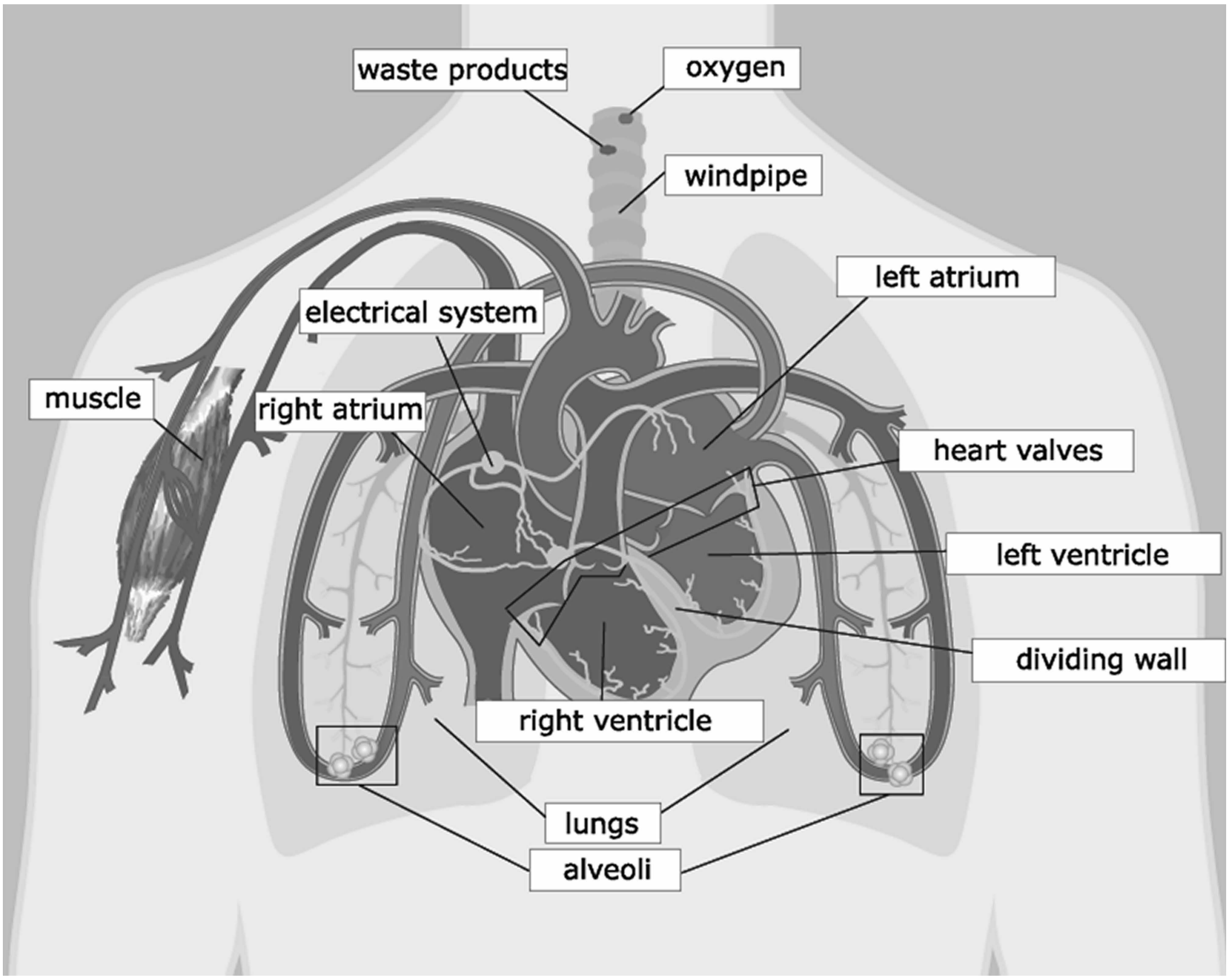


Figure 1 *Labeled diagram of the cardiovascular system*

Providing participants with structural knowledge of the cardiovascular system in a labeled diagram was done to ensure that all participants had learned the (same) prerequisite structural knowledge without which the self-explanation activity would be very difficult or perhaps be impossible. The static diagram was presented for 2 minutes at full-screen. To assess whether participants were able to correctly recall the labels and match them to the appropriate structures, an unlabeled static diagram was used. The only difference between the labeled and the unlabeled static diagrams was that in the unlabeled diagram the labels were omitted, and participants had to fill them out. To reduce the possibility that naming the structures could occur on the basis of (visual) short-term memory, participants completed an intermediate task that required them to count backwards as from 585 in steps of three for 1 minute (Peterson & Peterson, 1959). An acceptance criterion of 95 percent of correctly named structures was used for participants to continue with the experiment. If participants failed to meet this criterion, they were instructed to re-study the labeled diagram once and to fill out the unlabeled diagram again. Participants were discarded from the experiment if they did not meet the criterion after re-studying the materials. All participants did meet the criterion that was necessary to continue with the experiment.

Practice exercise

All participants were given a practice exercise before studying the animation of the cardiovascular system. It consisted of studying an animation of how lightning develops with or without self-explaining for 2 minutes. Participants in the self-explaining conditions were first given written instructions about self-explaining. Then they were instructed to self-explain during the animation in order to familiarize themselves with explaining aloud. In the no self-explaining conditions, participants only studied the animation without self-explaining. The practice exercise was developed to inform participants about the upcoming learning task (that it closely resembled) and to offer participants the opportunity to practice and familiarize themselves with studying an animation with or without self-explaining.

Animation

Two versions of an animation illustrating the workings of the human cardiovascular system were used in this study. The content in both versions was identical. That is, both versions depicted the simultaneous dynamics of the five main subsystems of the cardiovascular system: The circulatory system, the electrical system, the pulmonary circulation, the systemic circulation, and the valves system. Each subsystem has unique dynamic characteristics and serves a specific role in the cardiovascular system. Despite their individual properties and purposes, the subsystems are largely dependent on each other to let the cardiovascular system function correctly. In short, the animation showed how and where blood flows in the heart, where exchange of oxygen and waste products takes place, how the heart contracts, and how the heart valves and electrical system work. In total, the animation showed 26 cardiac cycles that each lasted approximately 12 seconds. It took 305 seconds to play the entire system-paced animation. The two versions of the animation were presented without accompanying written or verbal descriptions. Furthermore, the two versions contained no pauses, learners could not control its speed, its direction, and they could not stop the animation. The animation's speed was set at 9.5 frames per second. Prior testing indicated that this speed allowed for elaborated self-explanations, but was sufficiently challenging to prevent ceiling effects.

Despite identical content in all conditions, the only difference between the two versions of the animation was that in the cued version the five different subsystems were sequentially cued, whereas in the uncued version the animation was presented without visual cues. Cueing was done by decreasing the luminance of all elements in the animation except the cued subsystem. This visual contrast enables the cued subsystem to stand out against the rest of the animation and, therefore, to become more salient. Despite this change, all uncued elements of the animation were still visible and could be attended to. In the visual cueing conditions, each of the five subsystems was cued consecutively for 55 seconds with an inter-cueing period of 4.5 seconds in which the animation was not cued. Within each cueing period (i.e., 55 seconds), a single subsystem was cued and participants saw the cued subsystem in at least four cardiac cycles. Prior testing indicated that this duration of the cue was necessary for participants in the self-explanation conditions to be able to adequately elaborate on the cued subsystem. The first cue appeared on the screen twelve seconds after the start of the animation to ensure that participants would notice the visual contrast. Cueing followed a predetermined order (electrical system, circulatory system, pulmonary circulation, valves system, and systemic circulation). This order was derived from the way in which the cardiovascular system is usually described in medical textbooks.

In the self-explanation conditions, participants explained aloud the functioning of the -different parts of the- cardiovascular system while they viewed the animation. The cyclical nature of the animation allowed participants to self-explain during learning without having to miss essential information. Self-explaining did not increase the time on task, as participants were only allowed to self-explain while they watched the animation, which had a fixed duration that was the same for all conditions. Furthermore, the experimenter did prompt participants to continue explaining when their comments were vague, incomplete, or when participants paused for more than 5 seconds during the protocol. The prompts were based on the content-free prompts designed by Chi, Siler, Jeong, Yamauchi, and Hausmann (2001). The prompts did not give explanations, feedback, or other extra information to participants. They were only intended to encourage participants to elaborate on the content in the animation. Appendix C provides a list of examples of the prompts that were used. Moreover, prior to the experiment the experimenter was carefully instructed that he was not allowed to try to influence the learning process in any way and should provide the prompts in a neutral way. Further, the experimenter sat out of sight of the participants to minimize the change of any uncomfortable feelings or pressure to perform well participants may have felt in the presence of the experimenter. All verbal comments were recorded with a tape recorder.

Learning performance

To assess the participants' understanding of the cardiovascular system, a set of 32 retention questions, five transfer questions (De Koning et al., in press), and 14 inference questions were used. All questions covered information that was presented in the animation or tested the knowledge that could be inferred from it. Sample questions for the retention, inference, and transfer test are provided in Appendix B.

The retention test consisted of multiple-choice items with four alternatives. Retention questions asked learners about information that was explicitly displayed in the animation. Comparable number of questions covered the structural and behavioral aspects of each subsystem. An analysis of the animation in terms of the information that could be extracted from it was used to construct the test items. Hence, test items asked about all relevant elements of a subsystem and because only complete subsystems were cued the questions directly corresponded to information in a cued region. To minimize the risk that questions were not fully understood or completely misinterpreted, pictures were added that referred to elements mentioned in the question. Test items were only pictorial if the questions were difficult to interpret with text alone or to clarify a concept. For instance, one retention question asked participants to choose the picture that correctly shows the direction of blood flow out of four pictures.

The inference test consisted of open-ended questions. The questions were specifically designed to assess the participants' ability to infer causal relations from the animation. Correctly answering the questions required participants to combine and integrate information from -different parts of- the animation and to relate this to learned information. For example, one question asked, 'What causes the valves of the heart to open?' A correct answer to this question would require the participant to recognize that the closed valves prevent the blood from flowing directly from the upper chambers to the lower chambers of the heart, causing the upper chambers to increasingly build up pressure that, if high enough, opens the valves.

The transfer test consisted of open-ended questions. All transfer questions covered the workings of the subsystems shown in the animation. Each question asked participants to reason about the functioning of one of the five subsystems. These questions could only be answered correctly by applying the learned inferences about the cause-effect relations of the subsystems (i.e., cued parts) and, therefore, provides a good measure of the quality of the constructed representation (Mayer, 2001). An example of a transfer question is 'Explain why it is possible to divide the functioning of the electrical system into two steps.'

Mental effort

The mental effort measure used in this study was a 9-point subjective rating scale, ranging from very, very low mental effort (1) to very, very high mental effort (9), and was developed by Paas (1992). The scale's high reliability and validity, and its non-intrusive nature make the scale a useful measure of perceived working memory load (Paas, 1992; Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

Procedure

The experiment was conducted in 10 sessions of 90 minutes. In each session between 1 and 15 participants were tested, with participants randomly assigned to one of the experimental conditions. Each participant was seated at a computer and completed the experiment at his or her own pace. Participants completed the experiment individually, but in some sessions participants in the no-explaining conditions completed the experiment simultaneously. Nevertheless, the experimenter was present and carefully monitored the progress of each of the participants in all experimental conditions. When participants had finished the experiment, they could do something by themselves in silence, but they were not allowed to leave the classroom or talk to other students.

The purpose of the experiment was explained on the computer screen and an outline was given of the different parts of the experiment. First, the participants filled out the demographic questionnaire. Subsequently, they studied the labeled diagram in order to learn the names of the main structures of the cardiovascular system followed by an unrelated number-counting task and completed a fill-in exercise to test whether they met the 95 percent correct criterion to continue with the experiment. Participants then completed the practice exercise. Then, participants read instructions that stated that they should carefully study and try to comprehend the content of the animation, in order to be able to answer questions on subsequently given knowledge tests. Participants in the self-explanation conditions were also instructed to self-explain aloud while studying the animation. Depending on the experimental condition, one of the two versions of the animation was then presented on the computer screen. The animation was followed by a frame asking participants to indicate their invested mental effort by clicking on one of the options of the mental effort rating scale.

After a brief introduction to the test phase, participants were presented the inference questions that could be answered by typing their answer in an on-screen textbox by using the keyboard. The inference test was given before the retention test to ensure that the answers to the inference questions could not be influenced by the information provided in the multiple-choice retention questions. Subsequently, participants received the retention test. Retention questions could be answered by clicking on one of the four choice alternatives. Finally, participants completed the transfer questions, which they could answer using the keyboard. All test questions were individually and randomly presented on screen. Participants were able to sequentially move through the questions by clicking the 'next' button, but it was not possible to return to previously presented questions. Participants were allowed to take as much time as needed to answer each question. After each test, participants rated the invested mental effort.

Analysis

Learning performance

Participants' performance on the retention, inference, and transfer items was scored blind with respect to experimental condition. For each correct multiple-choice question on the retention test participants received one point, otherwise they received zero points. The maximum score was 26 points. The inference test was scored by the correct inferences for each question. For each correctly inferred relation on an inference question one point was awarded. Several questions required learners to make two inferences, yielding a maximum score of 23 points. The transfer questions were scored by counting the number of idea units that were included in the participant's answer. For each question, one point was assigned to each correctly mentioned idea unit. The maximum score was 21 points.

Self-explanation protocols

The participants' think-aloud protocols were transcribed and then coded according to a scheme based on Ainsworth and Burcham (2007). Modifications were made where necessary to adjust it to the present learning materials and the format of presentation. All verbal protocols were scored for segments that corresponded to one of the following categories (samples of real self-explanations for each category are provided in Appendix D):

1) *Paraphrase*: An utterance was coded as a paraphrase if the participants merely verbalized information that was visible or explicitly presented in the animation without adding new information in the form of an explanation. For example, the utterance '*blood flows from the atrium to the ventricle*' would be coded within this category.
2) *Goal-driven explanation*: Self-explanations were considered goal-driven if participants made explanations that inferred a goal or function to a particular action or structure of the cardiovascular system. For example, saying that '*valves close to prevent blood from flowing upwards*' would be attributing a purpose to the closing of the valves.
3) *Elaborative explanation*: If participants produced explanations that inferred information from the animation in an elaborated way, without assigning it a specific goal or purpose it was coded in this category. For example, the sentence '*blood in the muscle is oxygenated*' would be placed in this category.
4) *Monitoring statements*: These statements indicated whether participants did or did not understand the information presented in the animation and reflected checks on understanding, confusion, or questions about the learning material. For example, utterances such as '*I do not understand how the electrical system works*' or '*Okay, now I see why blood is traveling to the muscle*' are assigned to this category.
5) *Inference errors*: If participants made a self-explanation that reflected incorrectly inferred knowledge, it was referred to as an incorrect self-explanation. Ambiguous or partially correct inferences were not counted as errors. For example, the sentence '*Blood entering the muscles takes up oxygen, and then flows back into the right side of the heart*' was coded within this category because the purpose of the blood flow towards the muscles is inferred incorrectly.

Results

For all statistical tests, a significance level of .05 was applied. For any post-hoc analyses, we used analysis of variance (ANOVA). Effect sizes are expressed in terms of partial eta squared ($\eta_p{}^2$).

Learning outcomes

Table 1 shows the mean scores and standard deviations on the dependent measures for all conditions. A MANOVA on the learning performances of the retention test, the inference test, and the transfer test with the between-participants factors cueing (yes, no) and self-

Table 1 *Means (and standard deviations) on the dependent measures as a function of condition*

	Self-explaining				No self-explaining			
	Cued		Uncued		Cued		Uncued	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Learning Outcomes								
Retention test (0-26)	11.38	4.41	8.71	4.01	10.64	4.26	12.30	4.61
Inference test (0-23)	10.33	2.54	6.52	3.67	4.52	2.63	5.09	3.15
Transfer test (0-21)	2.57	2.56	1.05	1.12	0.92	1.22	1.00	1.31
Mental effort (ME)								
ME Animation (1-9)	5.57	1.99	4.86	2.01	5.44	2.22	4.71	2.08
ME Inference test (1-9)	5.81	2.06	6.00	1.41	6.48	2.04	5.91	1.68
ME Retention test (1-9)	6.19	2.21	6.33	1.39	6.68	1.57	6.22	1.70
ME Transfer test (1-9)	5.91	1.94	6.48	2.02	6.16	1.93	6.00	2.63
Instructional Efficiency (E)								
Retention	.17	1.10	-.32	.82	-.15	1.04	.30	1.12
Inference	.83	.947	.033	.92	-.53	1.02	-.21	.98
Transfer	.57	1.17	-.24	.91	-.19	.86	-.10	1.04

explaining (yes, no) revealed a significant main effect for self-explaining (Wilks' $\lambda = 0.54$, *F* (3,84) = 24.11, $p < .05$, $\eta_p^2 = .463$), and cueing (Wilks' $\lambda = 0.90$, *F* (3,84) = 3.17, $p < .05$, $\eta_p^2 = .102$), as well as a significant interaction-effect between cueing and self-explaining (Wilks' $\lambda = 0.87$, *F* (3,84) = 4.08, $p < .05$, $\eta_p^2 = .127$). To clarify the MANOVA results, separate analyses of variance (ANOVA) with the factors cueing (yes, no) and self-explaining (yes, no) were conducted for the performances on the retention test, the inference test, and the transfer test.

The ANOVA for performance on the retention test revealed no main effects of self-explaining (*F* (1,86) = 2.42, *MSE* = 18.77, $p > .05$, $\eta_p^2 = .027$) or cueing (*F* (1,86) = 0.30, *MSE* = 18.77, $p > .05$, $\eta_p^2 = .003$). However, the interaction between self-explaining and cueing was significant (*F* (1,86) = 5.59, *MSE* = 18.77, $p < .05$, $\eta_p^2 = .061$). Nevertheless post-hoc tests revealed no significant differences between any of the four conditions (*F* (1,86) = 5.59, *MSE* = 18.77, $p < .05$).

For performance on the inference test, the ANOVA results showed a significant effect of self-explaining, with the explaining conditions making significantly more inferences than the no-explaining conditions (*F* (1,86) = 32.35, *MSE* = 9.09, $p < .05$, $\eta_p^2 = .273$). The effect of cueing also reached statistical significance (*F* (1,86) = 6.47, *MSE* = 9.09, $p < .05$, $\eta_p^2 = .070$), with a higher number of inferences for the cued conditions than for the uncued conditions. The interaction between cueing and self-explaining, which is depicted in Figure 2, was significant (*F* (1,86) = 11.79, *MSE* = 9.09, $p < .05$, $\eta_p^2 = .121$). Post-hoc analyses showed that learners in the condition with self-explaining and cueing generated more inferences than learners in any of the other conditions (*F* (3,86) = 16.59, $p < .05$). The other comparisons revealed no significant differences. The interaction indicates that self-explaining yielded more correct inferences with spotlight-cues than without spotlight-cues, whereas for the no-explaining conditions no significant difference was found between spotlight-cues and no spotlight-cues.

Concerning the performance on the transfer test, the ANOVA showed a pattern that is analogous to the results on the inference test. A significant effect of self-explaining was found in the transfer test, indicating that learners in the explaining conditions obtained significantly higher scores than learners in the no-explaining conditions (*F* (1,86) = 6.04, *MSE* = 2.67, $p < .05$, $\eta_p^2 = .066$). In addition, there was a significant effect of cueing, with the cued conditions scoring significantly higher than the uncued conditions (*F* (1,86) = 4.36, *MSE* = 2.67, $p < .05$, $\eta_p^2 = .048$). Moreover, the interaction between self-explaining and cueing was significant (*F* (1,86) = 5.38, *MSE* = 2.67, $p < .05$, $\eta_p^2 = .059$). As Figure 3 illustrates, the separate group means show a superiority of explaining in the cued condition, but not in the uncued condition.

Post-hoc analyses revealed that self-explaining with spotlight-cues resulted in significantly higher transfer scores than self-explaining without spotlight-cues or studying the animation without generating self-explanations (*F* (3,86) = 5.07, $p < .05$). The other comparisons revealed no significant differences.

A MANOVA on the mental effort measures with cueing (yes, no) and self-explaining (yes,

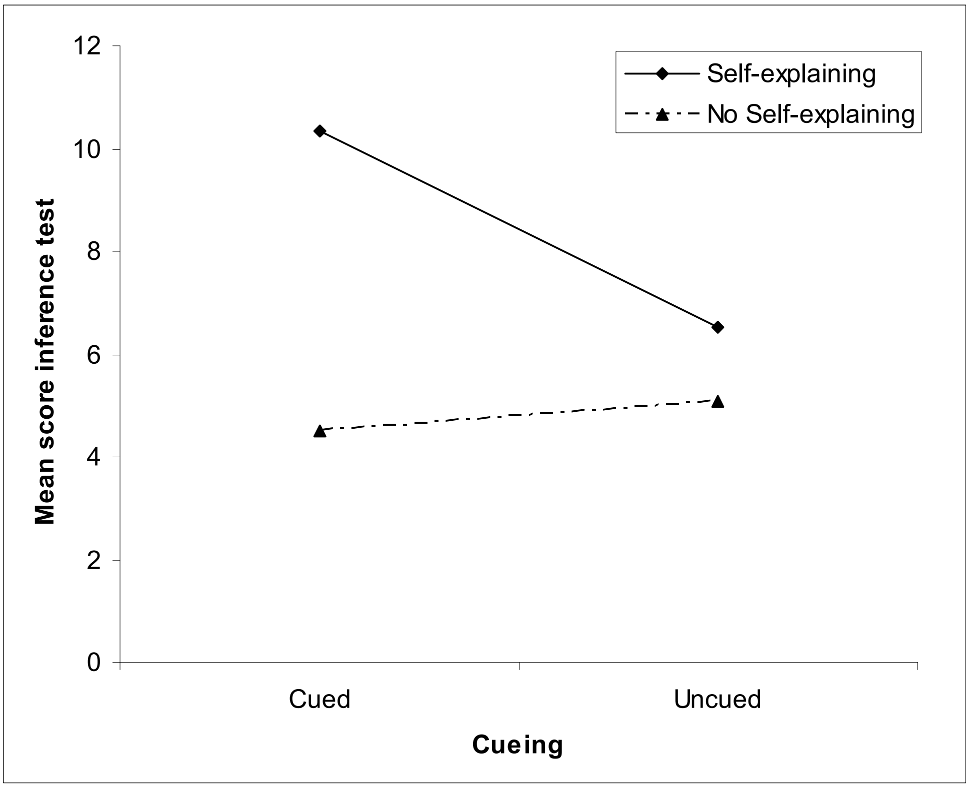


Figure 2 *The significant interaction effect between cueing and self-explaining on the inference test*

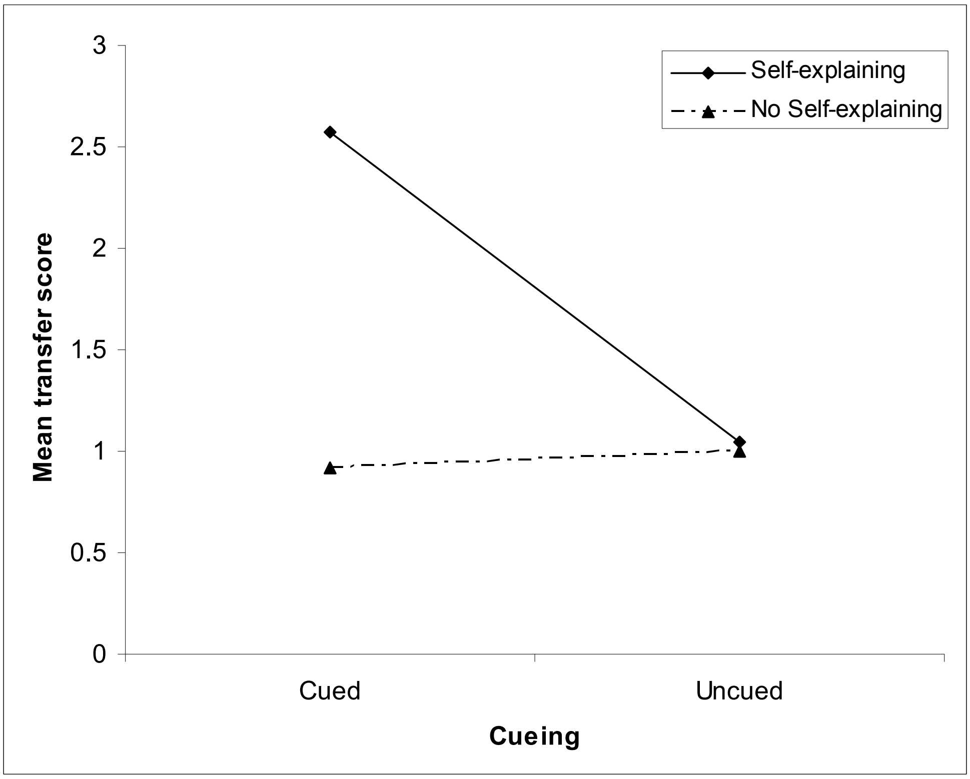


Figure 3 *The significant interaction effect between cueing and self-explaining on the transfer test*

no) as the between-participants factors revealed no significant differences on either self-explaining (Wilks' $\lambda = 0.98$, $F(4,83) = 0.42$, $p > .05$) or cueing (Wilks' $\lambda = 0.95$, $F(4,83) = 1.06$, $p > .05$), nor a significant interaction between self-explaining and cueing was observed (Wilks' $\lambda = 0.99$, $F(4,83) = 0.31$, $p > .05$). However, according to cognitive load theory, a meaningful interpretation of the level of cognitive load can only be given in the context of its associated performance level and vice versa. Consequently, in many studies measuring cognitive load it is common to take both measures into account because this gives a better account of the quality of the constructed cognitive schema than performance measures alone. Therefore, participant's test performance on the inference test, the retention test, and the transfer test and the mental effort invested during the performance of these tests were combined using the Paas and Van Merriënboer's (1993) computational approach to calculate instructional efficiency (E) on retention, inferences, and transfer.

A MANOVA on the efficiency scores for retention, inference, and transfer with cueing (yes, no) and self-explaining (yes, no) as the between-participants factors revealed a significant main effect for self-explaining (Wilks' $\lambda = 0.74$, $F(3, 84) = 10.02$, $p < .05$, $\eta_p^2 = .264$) as well as a significant interaction between self-explaining and cueing (Wilks' $\lambda = 0.91$, $F(3, 84) = 2.72$, $p < .05$, $\eta_p^2 = .088$). However, the main effect for cueing was not significant (Wilks' $\lambda = 0.95$, $F(3, 84) = 1.56$, $p > .05$). Separate ANOVAs on the efficiency scores for retention, inference, and transfer with cueing and self-explaining as the between participant factors showed a significant effect of self-explaining on the efficiency scores of the inference test ($F(1, 86) = 15.33$, $p < .05$, $\eta_p^2 = .151$), indicating that the explaining conditions were more efficient than the no-explaining conditions, that is, they obtained better performances on the inference test without investing more mental effort to obtain this performance. Moreover, there was a significant interaction between self-explaining and cueing for the efficiency scores on retention ($F(1, 86) = 4.65$, $p < .05$, $\eta_p^2 = .051$), inference ($F(1, 86) = 7.56$, $p < .05$, $\eta_p^2 = .081$), and transfer ($F(1, 86) = 4.49$, $p < .05$, $\eta_p^2 = .050$). Post-hoc analyses showed that the self-explaining with spotlight-cues condition was significantly more efficient on the inference test ($F(3, 86) = 8.03$, $p < .05$) and on the transfer test ($F(3, 86) = 4.65$, $p < .05$) than any of the other three conditions. The other comparisons revealed no significant differences. In short, the results on the efficiency scores largely parallel the results of the learning performance measures.

Self-explanations during learning

The learning outcome measures indicated that self-explaining with spotlight-cues resulted in better learning performance on the inference test and the transfer test than self-explaining without spotlight-cues. To gather more information on how cues affected the self-explanations during learning, the self-explanation protocols of participants in the two self-explaining conditions were analyzed according to the coding scheme described above. Two independent raters that were unaware of experimental condition scored a randomly selected sample of 30% of the verbal protocol data. To estimate the interrater reliability, we calculated Cohen's Kappa (k) on the pairs of scores in this subset. The results revealed a high interrater agreement (k = 0.88), and therefore one of the two raters scored the remaining protocols.

The influence of cueing on the verbalizations and the number of each type of self-explanation was analyzed by a MANOVA with cueing as the between-participants factor with paraphrases, goal-directed self-explanations, elaborative self-explanations, monitoring statements, incorrect self-explanations, number of words, and number of self-explanation prompts as dependent variables. It should be noted that monitoring statements only contained negative utterances as no positive monitoring statements were made. This analysis showed that cueing significantly influenced the characteristics of the learners' self-explanations (Wilks' $\lambda = 0.39$, $F\ (7{,}34) = 7.48$, $p < .05$). More specifically, the results, which are depicted in Table 2, show that participants in the cued self-explanation condition did not use significantly more words in their verbal protocols ($F\ (1{,}40) = 3.42$, $MSE = 11036.94$, $p > .05$), and did not receive more self-explanation prompts from the experimenter ($F\ (1{,}40) = 0.64$, $MSE = 18.09$, $p > .05$). In addition, there were no significant differences in the number of paraphrases ($F\ (1{,}40) = 0.11$, $MSE = 17.37$, $p < .05$). So, on the descriptive level, no significant differences were found between the cued and the uncued self-explanation conditions. However, as can be seen in Table 2, the self-explanation with spotlight-cues condition elicited significantly more elaborative self-explanations ($F\ (1{,}40) = 24.95$, $MSE = 6.57$, $p < .05$, $\eta_p^2 = .384$) and goal-directed self-explanations ($F\ (1{,}40) = 31.39$, $MSE = 2.13$, $p < .05$, $\eta_p^2 = .440$) than the self-explanation condition without spotlight-cues. In addition, the learners that self-explained with attention-directing cues generated fewer (negative) monitoring statements ($F\ (1{,}40) = 9.43$, $MSE = 1.46$, $p < .05$, $\eta_p^2 = .191$) and incorrect self-explanations ($F\ (1{,}40) = 4.72$, $MSE = 1.14$, $p < .05$, $\eta_p^2 = .105$) than the learners that had no such cues to facilitate the self-explanation process.

Table 2 *Mean number (and standard deviations) of type of self-explanations for the cued and uncued conditions*

	Self-explaining			
	Cued		Uncued	
	M	*SD*	*M*	*SD*
General				
Word count	350.62	123.27	290.67	82.94
Self-explanation prompts	12.76	4.15	13.10	4.36
Statements				
Paraphrases	13.86	4.36	14.29	3.69
Goal-driven self-explanation	3.86	1.80	1.33	1.02
Elaborative self-explanation	6.95	3.06	3.00	1.95
Monitoring	0.81	.087	1.95	1.47
Incorrect self-explanation	0.71	0.64	1.42	1.36

Table 3 *Interrelations between the types of self-explanation statements and learning outcome measures*

	1	2	3	4	5	6	7	8
(1) Retention test	-	0.66**	0.49**	-0.07	0.40**	0.28	-0.14	-0.23
(2) Inference test		-	0.57**	-0.06	0.60**	0.34*	-0.29	-0.31*
(3) Transfer test			-	-0.35*	0.51**	0.19	-0.22	-0.17
(4) Paraphrases				-	-0.16	-0.11	-0.03	0.23
(5) Goal-directed self-explanation					-	0.55**	-0.40**	-0.33*
(6) Elaborative self-explanation						-	-0.35*	-0.36*
(7) Monitoring							-	0.10
(8) Incorrect self-explanation								-

Note. *$p < 0.05$, **$p < 0.01$

To examine how the self-explanation data are related to the performance on the learning outcome measures, Pearson Correlation Coefficients were calculated for each type of self-explanation the participants generated and their scores on the retention test, inference test, and the transfer test (see Table 3). Both goal-directed self-explanations and elaborative self-explanations are positively related to the scores on the inference test, whereas goal-directed self-explanations also relate positively to retention test scores and transfer test scores. An increased number of self-explanation errors were associated with lower scores on the inference test. Further, higher transfer test scores were associated with fewer paraphrases.

Discussion

This study investigated the effects of generating self-explanations on learning from a complex animation with or without spotlight-cues. It was hypothesized that the learning performance when studying a cued animation would be enhanced by generating self-explanations, whereas generating self-explanations while studying an uncued animation would not enhance learning performance. As expected, the results of the present study show that learners who generated self-explanations with a cued animation yielded higher performance on inference and transfer (but not retention) tasks than learners who generated self-explanations with an uncued animation and learners who did not self-explain. Thus, the test performance of the learners in the self-explanation condition studying a cued animation indicates that they had developed a more thorough conceptual understanding of the causal relations between elements of the cardiovascular system. In addition, this allowed them to apply the learned information to novel tasks. Moreover, based on the combination of test performance and invested mental effort this condition seems most efficient for learning, that is, learners had a higher performance without investing more mental effort to obtain this performance. These findings extend the substantial literature showing that self-explaining is an effective strategy to improve learners' understanding of texts (e.g., Chi et al., 1994), diagrams (e.g., Ainsworth & Loizou, 2003), or the simultaneous presentation of textual and static graphical representations (e.g., Butcher, 2006). This study demonstrates that prompting learners to self-explain improves their understanding of an instructional animation without textual explanation. Moreover, in contrast to the majority of self-explanation studies where learners engage in elaborate training and practice of self-explaining (McNamara, 2004), the present study shows that even with minimal training and limited time to generate self-explanations, significant learning gains can be obtained. Whether this dissimilarity is due to differences in the processing demands of textual and graphical representations, is an issue for future research.

Further, the present findings extend the results of prior studies on learning from animations showing that a priori encouraging learners to invest more mental effort in relevant learning activities by a prequestion or having learners predict the next step in a process leads to better learning performance (Hegarty et al., 2003; Mayer, Dow, & Mayer, 2003). This study demonstrates that directly prompting learners to explain their thoughts while studying the animation improves their understanding, at least when the animation is cued. It might be argued that the superior performance with self-explaining is a bit overstated because of the dissimilarity between the individual testing in the self-explanation conditions and the group testing that sometimes occurred in the no self-explanation conditions. However, although there was a significant main effect for self-explanation, the effect was primarily explained by the significant interaction between cueing and self-explaining, which indicated better test performances for the cued self-explaining group, but not for the uncued self-explaining group. Furthermore, the combined results do not support the assumption that group testing, in general, has lead to a decrease in attention, motivation and effort in this study. More specifically, although non-explainers did perform worse than the self-explainers on the inference and transfer tests, their performance on the retention test was not, nor did they report lower mental effort scores. In conclusion, although we cannot exclude the possibility of confounding of test performance in the self-explanation condition, we believe that this is highly unlikely. Nevertheless, further research in which all participants are tested individually is needed to warrant any definite claims on this issue and on the implications concerning the generalizability of this finding.

Furthermore, the availability of attention-directing cues appears to influence the effectiveness of self-explanations. Spotlight-cues seem to enable learners to generate more meaningful self-explanations and to engage in useful comprehension processes and hence construct a deeper understanding. The content of the self-explanations may provide further insight into how conceptual understanding emerged. The self-explanation data suggest that, as predicted, cues elicited specific types of self-explanations that were related to comprehension processes and subsequent test score performance. Although learners in both self-explanation conditions generated adequate self-explanations, the animation with cues increased the frequency with which learners generated goal-driven and elaborative self-explanations (Ainsworth & Loizou, 2003). Further, the results suggest that attention-directing cues supported learners in generating correct inferences. The finding that certain types of active processing and hence the type of self-explanation statements largely influence learning performance is consistent with prior research on the self-explanation effect in text and/or diagrams (Ainsworth & Burcham, 2007; Butcher, 2006).

Although a higher frequency of integrative (goal-driven and elaborative) and correct explanations may explain why learners studying a cued animation outperformed learners studying an uncued animation, it does not provide an explanation as to why the combination of spotlight-cues and generating self-explanations was most effective at enhancing learning. One perceptual explanation may be that by automatically capturing attention, spotlight-cues circumvent the controlled visual search process during the selection and extraction of information depicted in the animation (De Koning et al., in press; Kriz & Hegarty, 2007). Consequently, the processing time to identify relevant elements is likely to be shortened and the opportunity to use mental resources for cognitive processes that are required for organizing and integrating the presented information into an adequate representation is increased, allowing the active processing of the animation in working memory (Mayer, 2001). Several fruitful studies in cognitive load research have provided related explanations for the effect of cueing by suggesting that cues reduce the ineffective or extraneous load that instructional materials impose on working memory and increase cognitive resources that are used for learning related activities or germane load (e.g., Paas Van Gerven & Wouters, 2007). However, as the applied mental effort measure used did not differentiate between mental effort due to perceived difficulty of the subject matter, the way of presentation of the instructional materials, and the cognitive engagement in relevant learning activities, the present study does not allow us to draw unequivocal conclusions in this regard. Therefore, based on the observation that in the present study the generation of important types of self-explanations was best in the cued self-explanation condition and that learning in this condition was most efficient (i.e., higher test performances without differences in mental effort), we can only assume that if self-explaining with a cued animation imposes some kind of cognitive load it is likely to be related to learning, effectively increasing cognitive engagement with the animation (i.e., germane load). Future studies are needed to explicitly test such capacity-related explanations.

Another explanation focuses on how the spotlight-cues were presented in the animation. The cued animations showed the different subsystems of the cardiovascular system consecutively. Therefore, the cues may have provided learners with a structured sequence of meaningful functional units of information. This allowed them to focus on and explain each part of the system depicted in the animation for themselves in more depth during a certain amount of time, and hence construct an accurate representation. However, in trying to understand the animation without cues, learners had to randomly select an element and shift from one location to the other, which may have hindered the process of generating self-explanations, especially if studying the animation occurred in an incoherent way. So, spotlight-cues may have provided a situation that is comparable to learning from text, where there is a well-defined structure, which learners can use to self-explain the material from beginning to end and increasingly improve their understanding. This explanation is consistent with Lowe and Boucheix' (2007) suggestion to emphasize the sequence of events in an animation in order to increase the opportunity that crucial aspects are noticed and subsequently will be further processed.

Both explanations for the effectiveness of spotlight-cueing are consistent with Butcher's (2006) observation that diagrams highlighting their essential parts and relations lead to more meaningful self-explanations and hence better conceptual understanding than diagrams in which crucial information is less salient. However, based on the results of the current study and the available evidence in prior research, an explanation for the effectiveness of spotlight-cueing in terms of structuring the learners' viewing pattern in order to guide their perceptual and cognitive processing seems most plausible. Future research is needed to substantiate this claim.

In contrast to the majority of animation studies that are conducted in a lab setting (for exceptions see e.g., Marbach-Ad, Rotbain, & Stavy, 2008), the current study was an attempt to investigate the effects of perceptual and cognitive manipulations in learning from an animation in a classroom setting. The use of a non-narrated and non-interactive animation and the absence of supplementary materials such as introductory texts made it possible to exert, to a large extent, control over the manipulated factors in our study. Consequently, this allowed us to ascribe the observed effects mainly to our experimental manipulations. However, we are aware that this approach does not exactly correspond to a regular classroom situation and largely constrains the generalizability of the findings for real teaching situations. Therefore, a replication of the experiment in a real learning environment in which the animation is integrated in the curriculum and where is less control over its features would be needed to further strengthen our conclusions. Nevertheless, we believe that controlled classroom studies provide a necessary and important step towards investigating the effects of learning from animations embedded in a real learning situation. These kinds of studies (including the present study) may identify specific conditions under which learning from animations may be enhanced that subsequently can be tested in more ecologically valid contexts such as an existing educational program.

Moreover, further research is required to examine whether the present findings can be generalized more broadly to longer educational tasks, to different types of animations (e.g., non-cyclical), using different types of cueing (e.g., arrows), and applying other active processing strategies (e.g., asking questions). Specifically, the type of animation used in this study might have been a major determinant in finding the observed effects on learning. The cyclic nature of the animation may have facilitated the generation of self-explanations because learners could iteratively view -individual parts of- the animation and hence could monitor their current understanding and update their mental representation accordingly. It is unclear whether viewing a non-cyclical animation, in which information cannot be re-inspected and thus might be easily missed or partly processed, will have similar effects on learning. In addition, it is often argued that learner control is an effective method for improving learning from animations (Tversky et al., 2002). It remains to be investigated whether providing interactivity (e.g., rewind, stop, and replay) that allows learners the freedom to manipulate an animation may lead to different learning performances when self-explaining with a cued or uncued animation. Especially, investigating the combination of cueing and learner control would be relevant because recent research has demonstrated that providing learners with control over an animation does not necessarily improve learning performance, whereas seeing the most task-relevant information does, regardless of whether the task-relevant information was obtained with or without learner control (Keehner, Hegarty, Cohen, Khooshabeh, & Montello, in press). In addition, presenting the animation without textual explanations may have provided a productive situation for enhancing conceptual understanding with self-explaining. That is, generating verbal self-explanations might improve understanding while viewing a visual-only animation as it encourages learners to integrate visual (i.e., animation) and verbal (i.e., self-explanations) representations. In contrast, when the instructional material and the self-explanations use the same underlying form of representation (e.g., text), such as when generating verbal self-explanations while viewing an animation with spoken or written text, self-explaining is less effective at promoting deeper understanding (see Cox, 1999). Future studies should therefore focus on how various attention-guiding techniques and learning strategies influence learning from different types of animations.

In sum, the results of this study suggest that presenting learners with a complex instructional animation without spotlight-cues and stimulating them to engage in relevant learning activities to achieve understanding is insufficient to obtain improved learning performances. Effective learning requires that learners are supported by attention-directing cues in selecting information that will subsequently serve as the basis for essential cognitive processing. Therefore, a practical implication resulting from this study is that we should design animations that support the processing of critical information in order to effectively verbalize the operation of a dynamic system and to foster learning. Self-explaining can be an effective cognitive tool to enhance learning from a complex instructional animation without text provided that the animation is designed to highlight and structure essential components and their (causal) relations that are necessary to understand the depicted system.

Chapter 6

Learning by generating versus receiving instructional explanations: Two approaches to enhance attention cueing in animations[5]

[5] This chapter is submitted for publication as: De Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2009). *Learning by generating versus receiving instructional explanations: Two approaches to enhance attention cueing in animations*. Manuscript submitted for publication.

Abstract

This study investigated whether learners construct more accurate mental representations from animations when instructional explanations are provided via narration than when learners attempt to infer functional relations from the animation through self-explaining. Also effects of attention guidance by means of cueing are investigated. Psychology students were given retention, inference, and transfer tests after studying a cued or an uncued animation of the cardiovascular system with learner-generated self-explanations or with externally provided instructional explanations. Results indicated that cued animations were more effective than uncued animations. Furthermore, results on retention and transfer indicated no differences between self-explaining and providing instructional explanations, but instructional explanations accompanying animations led to higher inference scores. It is concluded that whether explanations are generated or presented may be less important than the provision of cues that enable focused processing of presented or produced explanations.

Introduction

As with any comprehension task, the ultimate goal of understanding dynamic systems is to construct an integrated mental model that accurately represents the objects and the causal relations depicted in an external representation (Hegarty, Kriz, & Cate, 2003). Due to their capacity to explicitly depict movement, changes, and object trajectories in a single visual display, animations may provide a realistic representation of the workings of a complex dynamic system and therefore seem very well suited for teaching change-related information. To construct an integrated knowledge representation from animations, learners are required to identify the visual features from the visual display, relate corresponding elements in a single representation or from multiple representations with each other, and, perhaps most important to gain conceptual understanding, should go beyond simply looking at the information that is explicitly displayed in animations in order to extract and understand the underlying functional relations from the depicted system (Mayer, 2001).

However, research on the use of animation to facilitate learning about dynamic processes has shown that learners often fail to reach a thorough conceptual understanding of the presented information and may only learn from animations under very specific conditions (Höffler & Leutner, 2007). Several researchers have therefore concluded that animations may not necessarily be more effective than static graphics at teaching learners about dynamic processes (e.g., Tversky, Morrison, & Bétrancourt, 2002). In the present study, we examined whether *providing* instructional explanations through self-explaining (Chi, de Leeuw, Chiu, & LaVancher, 1994) and *receiving* instructional explanations via narration (Wittwer & Renkl, 2008) might support learners in their attempts to process animations more deeply, that is, engage in generative (or germane) processing (Mayer, 2005; Sweller, 1999) so that the learner will gain a better understanding of the causal relations that are depicted in the animation and will perform better on subsequent tests of learning (e.g., transfer test). Moreover, it is studied whether such explanations need to be supported by visual cues that guide attention to relevant parts of the animation.

Guiding attention in complex animations

According to Tversky et al. (2002), learning from animations might be hindered because the content of animations is often too complex to be accurately perceived. In line with this suggestion, several studies highlight the importance of visual attention in selecting and understanding graphical information (e.g., Canham & Hegarty, in press; Grant & Spivey, 2003). In animations, the simultaneous depiction of multiple changes and the transitory nature of the presented information might have a considerable influence on what locations learners look at and when they look at it (Schnotz & Lowe, 2008). Lowe (1999) demonstrated that novice learners have difficulties in the identification and subsequent processing of relevant elements in animations, because their attention is often diverted by superficial features such as bright colors and fast movements that are not necessarily relevant for understanding the content. According to Ayres and Paas (2007) consciously distinguishing between relevant and irrelevant information in order to locate task-relevant information, and relating corresponding elements between different representations (e.g., animation and text) may cause high processing demands on the learners' working memory resources that do not contribute to learning (i.e., extraneous cognitive load). Consequently, extensively engaging in these unnecessary cognitive processes may leave (too) little working memory resources available for processes related to learning such as going beyond the information that is explicitly displayed in order to extract the functional relations (i.e., germane cognitive load, Paas, Renk, & Sweller, 2003).

By providing the learner with visual cues, relevant aspects in an animation can be highlighted, for example by increasing the visual contrast of relevant elements compared to their surrounding visual area (De Koning, Tabbers, Rikers, & Paas, 2009). This cueing approach assumes that directing attention to task-relevant information may improve learning by making it easier for learners to find key aspects of the subject matter. Thereby, visual search processes are reduced, which increases the availability of working memory resources for trying to understand the content and the underlying principles. Some of the cueing approaches have produced improved learning from animations (e.g., Boucheix & Lowe, in press).

However, there is increasing evidence that making salient which elements are relevant may guide attention to the cued element but does not ensure that the underlying causal structure needed for conceptual understanding is learned accurately (De Koning, Tabbers, Rikers, & Paas, in press; Kriz & Hegarty, 2007; for an overview see De Koning et al., 2009). A potential reason for the failure to find improved learning from cued animations might be that simply guiding attention to relevant locations on a surface level (e.g., coloring parts) does not necessarily encourage learners to spontaneously process the functional relations further on a conceptual level (e.g., underlying principles of the functional model). Similar related proposals have been put forward in learning from multiple external representations (MERs) in order to explain the failure to find improved learning from text and pictures with relational cues that provide a direct visible link between both information sources (Berthold & Renkl, 2009; Seufert & Brünken, 2004). Therefore, it is suggested that attention-directing cues seem very helpful to assist learners in focusing their attention on specific parts of an animation, but such cues are not sufficient to stimulate learners to engage in the active knowledge construction necessary for learning.

Increasing conceptual understanding of cued animations

Hence, stimulating learners to actively process the information presented in a cued animation will increase the probability that they will not only study the animation at a descriptive level but will also extract the functional relations that are depicted in the animation (Mayer, 2001). In a recent study, De Koning, Tabbers, Rikers, and Paas (submitted) demonstrated that prompting learners to explain to themselves why particular movements and changes in an animation occur, and what this information implies (i.e., self-explaining, Chi, Bassok, Lewis, Reimann, & Glaser, 1989) may improve understanding of a dynamic system's functioning. Participants who self-explained while studying a cued animation of the cardiovascular system made more correct inferences and had higher transfer performances than learners who generated self-explanations without cues (for similar findings see Butcher, 2006). These findings suggest that learners may be able to extract a dynamic system's functional relations if they are prompted to generate self-explanations, provided that they have sufficient working memory resources to engage in generative processing due to cues. The generative nature (Lovett, 1992; Slamecka & Graf, 1978) and the ongoing and continuous character of self-explaining provides learners that engage in more focused cognitive activities (Renkl & Atkinson, 2007) an opportunity to gradually build up and revise an understanding of the cued parts and ultimately an internal representation of the system as a whole.

However, even though self-explaining can be beneficial for learning, this is not necessarily the case for all learners as benefits depend on whether they are able to generate explanations that are helpful to overcome knowledge gaps as well as on the quality of their self-explanations to improve learning (Renkl, 1997). Moreover, simply asking novice learners to engage in the activity of providing self-explanations may not result in the construction of an integrated mental representation due to too high demands on the learners' working memory resources (Paas et al., 2003; Renkl & Atkinson, 2003). Thus, self-explaining may not ensure that learners extract all functional relations accurately, which may leave learners with incomplete or incorrect knowledge especially if no feedback is provided by an external source (Renkl, 2002).

Therefore, providing the functional relations to learners as a narrated explanation rather than requiring learners to come up with these inferences themselves may be more effective at improving the construction of an accurate mental representation from animations (cf. Wittwer & Renkl, 2008). According to Renkl (2002), instructional explanations may contribute to learning because they contain correct information and can serve as an external information source that provides help to overcome problems in understanding. These characteristics of instructional explanations seem to have some advantages over self-explaining with an animation and may thus be very helpful for learners who are required to develop an adequate understanding of the crucial functional relations of a dynamic system via animations.

However, instructional explanations may also have disadvantages that may hinder learning (Gerjets, Scheiter, & Catrambone, 2006; Schworm & Renkl, 2006; Wittwer & Renkl, 2008). Providing a narration that explains a dynamic system's functional relations does not necessarily require learners to integrate both information sources as listening to the explanatory information in the narration may be sufficient to build an accurate functional model of the depicted system. In addition, if a link is needed between spoken explanation and the animation and if learners are unable to sufficiently quickly establish such a link, integration of different representations into a coherent mental representation is hindered. Visual cues may then be necessary to facilitate learning (cf. Kalyuga, Chandler, & Sweller, 1999).

The present study

In this study, we presented learners a cued or an uncued animation about the cardiovascular system and varied whether learners generated self-explanations or received instructional explanations. Cueing consisted of consecutively highlighting the main subsystems of the depicted system and was intended to focus attention on relevant information. The learners that were instructed to self-explain during the animation could therefore immediately focus their attention on a relatively small area of the animation (i.e., a subsystem). Consequently, the visual search for relevant parts is likely to be reduced thereby increasing working memory resources for generating meaningful self-explanations (see De Koning et al., submitted). On the other hand, highlighting a subsystem at the moment that the information in the narration explains the functioning of that specific part of the animation may encourage learners to make a connection between corresponding elements in the two representations. If less time is needed to search for related elements between representations, learners have more working memory resources available for concentrating on understanding the textual explanation and the animation.

Based on this analysis, we expected a significant main effect of cueing, indicating that learners who self-explained or received instructional explanations while studying a cued animation would improve their memory and understanding of the animation yielding higher performance on retention, inference and transfer than learners studying an uncued animation (see Butcher, 2006; De Koning et al., submitted).

Furthermore, self-explanations are often fragmented (Roy & Chi, 2005), partially correct or even incorrect (Renkl, 2002), whereas the instructional explanations contain all correct functional information about the cardiovascular system. Therefore, learners who study the animation with accompanying instructional explanations may be more likely to learn all inferences than learners who had to rely on their own self-explanations while studying the animation. Consequently, we hypothesized that learners who studied the animation with an accompanying instructional explanation would have higher performances on the inference and retention test than learners who generated self-explanations during the animation. Moreover, as learners who studied an animation with accompanying narration receive all inferences, they should be able to build a more accurate mental representation of the depicted system than learners who generate self-explanations. Therefore, we also expected that the narrated animation groups would score higher on transfer than learners who self-explained with the animation.

As current theories on learning and instruction such as cognitive load theory suggest that the amount of learners' working memory resources may play an important role in the quality of the constructed mental representation, we also measured mental effort during the experiment. Furthermore, we also examined the self-explanation protocols to see how many functional inferences are generated and to determine the correctness of the self-explanations. In addition, we examined whether self-explaining with a cued or an uncued animation elicited qualitatively different self-explanations.

Method

Participants and design

The participants were 76 psychology undergraduates (20 males and 56 females) from the Erasmus University Rotterdam. Their mean age was 20.38 years (SD = 2.36). All participants were native Dutch speakers and received partial course credit for their participation. Participants had normal or corrected to normal vision, were unaware as to the exact purpose of the study, and gave informed consent. None of the participants had taken college level biology classes, but all had taken introductory courses on biology in high school that included the cardiovascular system and its basic components.

As a first independent variable, the amount of attention guidance to specific parts of the animation was varied between participants. In the animation the five main subsystems of the cardiovascular system were sequentially cued or not. As a second independent variable, the strategy to achieve conceptual understanding was varied between participants. Participants tried to understand the cardiovascular system by providing explanations about its functioning through self-explaining or by receiving explanations about its functioning via instructional explanations. Participants were randomly assigned to one of the four resulting conditions: A condition with visual cueing and self-explaining, a condition with visual cueing and instructional explanations, a condition without visual cueing and with self-explaining, and a condition without visual cueing and with instructional explanations. Three participants (one in the cued self-explanation condition and two in the uncued self-explanation condition) were eliminated from further analysis due to loss of data, leaving 18 participants in cued self-explaining condition, 17 in the uncued self-explaining condition, 19 in the cued instructional explanation condition, and 19 in the uncued instructional explanation condition.

Materials and apparatus

The computer-based learning environment consisted of a prior knowledge questionnaire, an animation, a static diagram, a cognitive load rating scale, a retention test, an inference test, and a transfer test. It was developed with Macromedia Flash 7.0 (Macromedia, 2004). The materials were electronically presented on a 19” LCD color computer screen with a resolution of 1280 × 1024 pixels. With the exception of the self-explanation data, all data were automatically recorded.

Prior knowledge questionnaire

The experiment started with a demographic questionnaire in which participants were asked to indicate their gender, age, years of university education, and experience with the cardiovascular system.

Furthermore, prior knowledge of and experience with the cardiovascular system and biology were assessed with a questionnaire, which was based on Mayer and Moreno’s

(1998) questionnaire, consisting of five items. Participants were asked to rate their prior knowledge of the cardiovascular system with one Likert-type item on a 5-point scale ranging from 1 (very little) to 5 (very much). The other four items, in the form of a 4-item checklist, regarded their experience with biology and the cardiovascular system. For example, participants were asked whether they had followed biology classes during their secondary education or whether they knew someone in their inner circle with a heart condition. All five prior knowledge items were added up to get a score, indicating overall knowledge of the cardiovascular system, ranging from 1 (no experience) to 14 (high experience). Analysis of the prior knowledge score indicated no significant differences between the cued self-explaining condition ($M = 4.11$, $SD = 1.85$), the uncued self-explaining condition ($M = 4.82$, $SD = 1.78$), the cued instructional explanation condition ($M = 5.53$, $SD = 1.65$), and the uncued instructional explanation condition ($M = 5.05$, $SD = 2.20$), $F(3, 69) = 1.81$, $MSE = 3.54$, $p > .05$.

Static diagram

In all conditions, participants studied a labeled static diagram which showed a colored picture of the cardiovascular system in a relaxing state and included labels naming the parts of the system (see Figure 1). For the labels, general terms (e.g., valves) instead of the specific terminology (e.g., tricuspid valve) were chosen to represent the structures of the cardiovascular system, because naming the system's structures in general terms avoids confusing different terms for the same concept. The purpose of the static labeled diagram was to provide participants prerequisite structural knowledge of the cardiovascular system without which the self-explanation activity would be very difficult or perhaps be impossible. The static diagram was presented for 2 minutes at full- screen. To assess whether participants were able to correctly recall the labels and match them to the appropriate structures, an unlabeled static diagram was used. The only difference between the labeled and the unlabeled static diagrams was that in the unlabeled diagram the labels were omitted, and participants had to fill them out. Furthermore, to reduce the possibility that naming the structures could occur on the basis of (visual) short-term memory, participants completed an intermediate task that required them to count backwards as from 585 in steps of three for 1 minute (Peterson & Peterson, 1959). An acceptance criterion of 95 percent of correctly named structures was used for participants to continue with the experiment. If participants failed to meet this criterion, they were instructed to re-study the labeled diagram once and to fill out the unlabeled diagram again. Participants were discarded from the experiment if they did not meet the criterion after re-studying the materials. All participants did meet the criterion that was necessary to continue with the experiment.

Practice exercise

All participants were given a practice exercise before studying the animation of the cardiovascular system. It consisted of studying an animation of how lightning develops

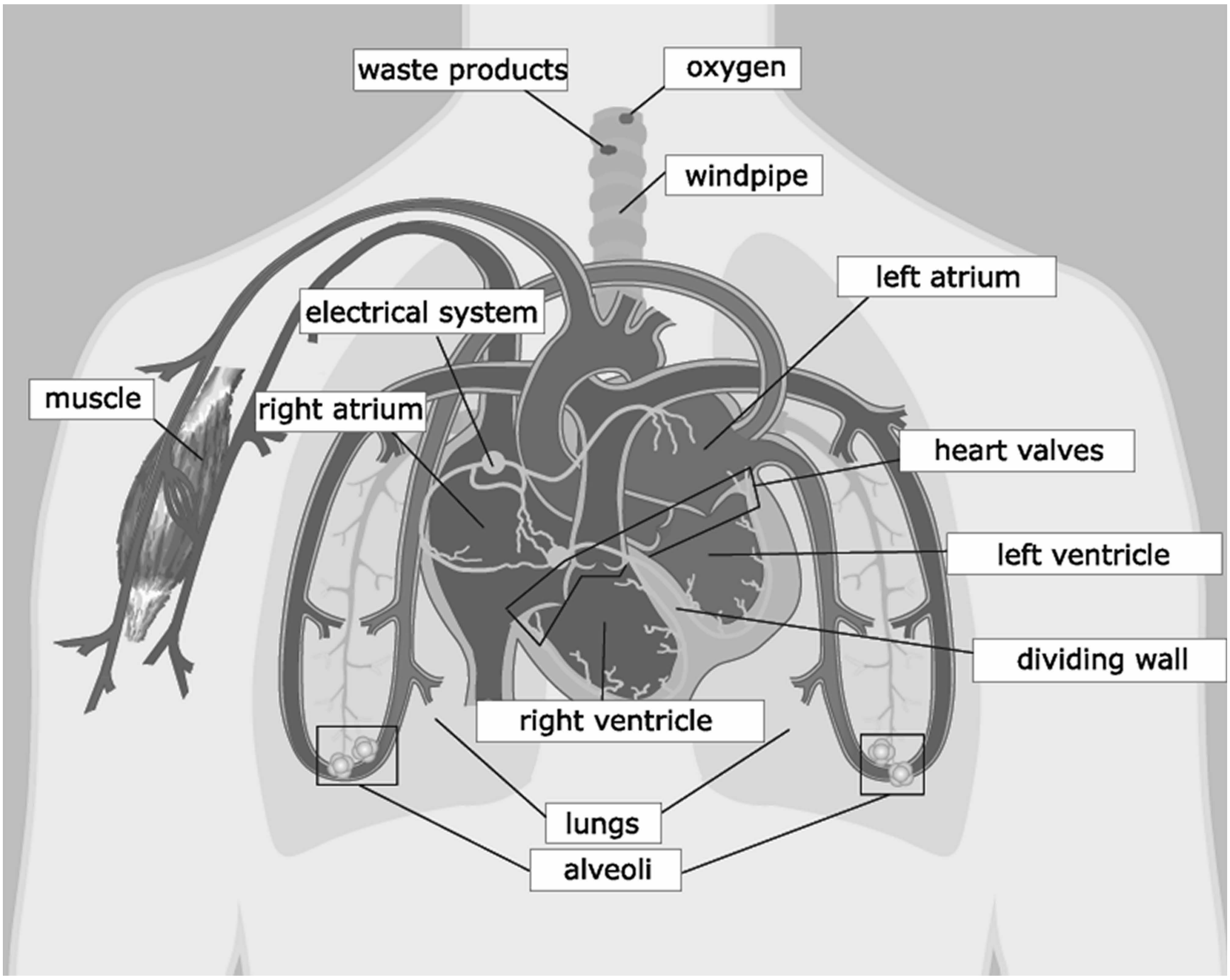


Figure 1 *Labeled diagram of the cardiovascular system*

(Mayer & Moreno, 1998) with self-explaining or accompanied by an instructional explanation for 2 minutes. The practice exercise was developed to inform participants about the upcoming learning task (that it closely resembled) and to allow participants to practice and familiarize themselves with studying an animation with self-explaining or with an instructional explanation.

Animation

Four versions of an animation illustrating the workings of the human cardiovascular system were used in this study. The content in all versions was identical. That is, all four versions depicted the dynamics of the five main subsystems of the cardiovascular system: The circulatory system, the electrical system, the pulmonary circulation, the systemic circulation, and the valves system. Each subsystem has unique dynamic characteristics and serves a specific role in the cardiovascular system. Despite their individual properties and purposes, the subsystems are largely dependent on each other to let the cardiovascular system function correctly. In short, the animation showed how and where blood flows in the heart, where exchange of oxygen and waste products takes place, how the heart contracts, and how the heart valves and electrical system work. In total the animation showed 22 cardiac cycles that each lasted approximately 13 seconds. It took 286 seconds to play the entire animation.

Furthermore, the four versions contained no pauses, learners could not control its speed, its direction, and they could not stop the animation. The animation's speed was set at 8.5 frames per second. Prior testing indicated that this speed was necessary for a good pacing of the narration in the instructional explanation conditions and for elaborated self-explanations in the self-explanation conditions, but the speed was sufficiently challenging to prevent ceiling effects in learning outcomes.

Despite identical content in all conditions, the four versions of the animation differed in two ways. First, the animation in the self-explanation conditions was presented without textual information, whereas the animation in the instructional explanation conditions was presented with an auditory narration that explained the workings of the cardiovascular system. The design of the instructional explanation was based on a careful task analysis conducted by the authors to ensure that it provided information that was relevant to the functioning of each part of the cardiovascular system, without being redundant to the animation. That is, the textual explanation delivered the functional information that explained the functioning of the different parts of the cardiovascular system, but comprised little structural and temporal information as this was already explicitly depicted in the animation (Scheiter & Schmidt-Weigand, 2008). The textual explanation only contained information that could be inferred form the animation resembling a perfect self-explanation. Thus, learners needed both representations and had to actively integrate the two representations to gain complete understanding of how the system works. The textual explanation was presented in digitized speech spoken in a female voice and was synchronized with the animation (contiguity principle, Mayer & Anderson, 1992). The presentation of the animation as well as the narration was system-paced.

Second, the difference between the cued and the uncued animations was that in the cued versions the five subsystems were sequentially cued, whereas in the uncued version the animation was presented without cues. Cueing was done by decreasing the luminance of all elements in the animation except the cued subsystem. This visual contrast enables the cued subsystem to stand out against the rest of the animation and, therefore, to become more noticeable. Despite this change, all uncued elements of the animation were still visible and could be attended to. Because some subsystems contain more causal relations than others and hence require more explanation, the cueing duration of a subsystem was determined by the amount of information that was explained about it in the narration. That is, the longer the narration about a subsystem and hence the more complex the required inferences about a subsystem, the longer the cueing duration for that specific subsystem. The cueing durations for each of the five subsystems ranged approximately from 40 seconds to 56 seconds: The electrical system was cued for 41.2 seconds, the circulatory system was cued for 57.3 seconds, the pulmonary circulation was cued for 55.8 seconds, the valves system was cued for 51.8 seconds, and the systemic circulation was cued for 49.3 seconds. Between the cued subsystems, there was an inter-cueing period of 3.9 seconds in which none of the subsystems was cued. Prior testing indicated that these durations of the cues were necessary for presenting the textual information per cued subsystem at a rate that allowed participants in the instructional explanation conditions to comprehend the textual information. Moreover, these cueing durations allowed participants in the self-explanation conditions to adequately elaborate on the cued subsystem. The first cue appeared on the screen fifteen seconds after the start of the animation to ensure that participants would notice the visual contrast. Cueing followed a predetermined order (electrical system, circulatory system, pulmonary circulation, valves system, and systemic circulation). This order was derived from the way in which the cardiovascular system is usually described in medical textbooks.

In the self-explanation conditions, participants explained aloud the functioning of the - different parts of the- cardiovascular system while they viewed the animation. The cyclical nature of the animation allowed participants to self-explain during learning without having to miss essential information. Self-explaining did not increase the time on task, as participants were only allowed to self-explain while they watched the animation, which had a fixed duration that was the same for all conditions. Furthermore, the experimenter did prompt participants to continue explaining when their comments were vague, incomplete, or when participants paused for more than 5 seconds during the protocol. The prompts were based on the content-free prompts designed by Chi, Siler, Jeong, Yamauchi, & Hausmann (2001). The prompts did not give explanations, feedback, or other extra information to participants. They were only intended to encourage participants to elaborate on the content in the animation. Appendix C provides a list of examples of the prompts that were used. All verbal comments were recorded with a tape recorder. In contrast to the self-explaining conditions, participants in the instructional explanation conditions were not explicitly encouraged to actively process the presented information by generating self-explanations but were only instructed to try to comprehend the functioning of the cardiovascular system based on the animation and the narration.

Learning performance

To assess the participants' understanding of the cardiovascular system, a set of 32 retention questions, 14 inference questions, and five transfer questions were used. All questions covered information that was presented in the animation or tested the knowledge that could be inferred from it. Sample questions for each test can be found in De Koning et al. (submitted).

The retention test consisted of multiple-choice items with four alternatives. Retention questions asked learners about structural and temporal information that was explicitly displayed in the animation. Comparable number of questions covered the structural and temporal aspects of each subsystem. An analysis of the animation in terms of the information that was depicted was used to construct the test items. To minimize the risk that questions were not fully understood or completely misinterpreted, pictures were added that referred to elements mentioned in the question. Test items were only pictorial if the questions were difficult to interpret with text alone or to clarify a concept. For instance, one retention question asked participants to choose the picture that correctly shows the direction of blood flow out of four pictures.

The inference test consisted of open-ended questions. The questions asked about the 23 functional relations in the animation, which were also provided in the narration or could be inferred in the self-explanation conditions. Correctly answering the questions required participants to combine and integrate information from -different parts of- the animation and to relate this to learned information. For example, one question asked, 'What causes the valves of the heart to open?' A correct answer to this question would require the participant to recognize that the closed valves prevent the blood from flowing directly from the upper chambers to the lower chambers of the heart, causing the upper chambers to increasingly build up pressure that, if high enough, opens the valves.

The transfer test consisted of open-ended questions. All transfer questions covered the workings of the subsystems shown in the animation. Questions asked participants to reason about the functioning of the cardiovascular system as a whole. These questions could only be answered correctly by applying the learned inferences about the cause-effect relations of the subsystems (i.e., cued parts) and, therefore, provides a good measure of the quality of the constructed representation (Mayer, 2001). An example of a transfer question is 'Explain why it is possible to divide the functioning of the electrical system into two steps.'

Mental effort

The amount of mental effort it took for participants to complete each task was measured on a 9-point subjective rating scale, ranging from very, very easy (1), to very, very difficult (9), which is known to give a reliable and valid indication of experienced complexity of the task at hand (Paas, 1992; Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

Procedure

Participants were tested in an individual session of approximately 60 minutes, with participants randomly assigned to experimental condition. Participants were seated at a computer. In the instructional explanation conditions the computer was also equipped with headphones. The purpose of the experiment was explained on the computer screen and an outline was given of the different parts of the experiment. First, the participants completed the prior knowledge questionnaire. Participants then completed the practice exercise. Participants in the self-explaining conditions were first given written instructions about self-explaining. Next, they were instructed to self-explain during the practice animation in order to familiarize themselves with explaining aloud. In the instructional explanation conditions, participants studied the practice animation with an instructional explanation. Subsequently, participants studied the labeled diagram in order to learn the names of the main structures of the cardiovascular system followed by an unrelated number-counting task and completed a fill-in exercise to test whether they met the 95 percent correct criterion to continue with the experiment. Then, participants read instructions that stated that they should carefully study and try to comprehend the content of the animation, in order to be able to answer questions on subsequently given knowledge tests. Participants in the self-explanation conditions were also instructed to self-explain aloud while studying the animation. Depending on the experimental condition, one of the four versions of the animation was then presented on the computer screen. The animation was followed by a frame asking participants to indicate their invested mental effort by clicking on one of the options of the mental effort rating scale.

After a brief introduction to the test phase, participants were presented the inference questions that could be answered by typing their answer in an on-screen textbox by using the keyboard. Subsequently, participants received the retention test. Retention questions could be answered by clicking on one of the four choice alternatives. Finally, participants completed the transfer questions, which they could answer using the keyboard. All test questions were individually and randomly presented on screen. Participants were able to sequentially move through the questions by clicking the 'next' button, but it was not possible to return to previously presented questions. Participants were allowed to take as much time as needed to answer each question. After each test, participants rated the invested mental effort.

Analysis

Learning performance

Participants' performance on the retention, inference, and transfer items was scored blind with respect to the experimental condition. For each correct multiple-choice question on the retention test participants received one point, otherwise they received zero points. The maximum score could be 26 points. The inference test was scored by the correct inferences for each question. For each correctly inferred relation on an inference question one point was awarded. Several questions required learners to make two inferences, yielding a maximum score of 23 points. The transfer questions were scored by counting the number of idea units that were included in the participant's answer. For each question, one point was assigned to each correctly mentioned idea unit. The maximum score was 21 points.

Self-explanation protocols

The participants' think-aloud protocols were transcribed and then coded according to a scheme based on Ainsworth and Burcham (2007). Modifications were made where necessary to adjust it to the present learning materials and the format of presentation. All verbal protocols were scored blind with respect to experimental condition for segments that correspond to one of the following categories:

1) *Paraphrase*: An utterance was coded as a paraphrase if the participants merely verbalized information that was explicitly depicted in the animation without adding new information in the form of an explanation. For example, the utterance '*blood flows from the atrium to the ventricle*' would be coded within this category.
2) *Goal-driven explanation*: Self-explanations were considered goal-driven if participants made explanations that inferred a goal or function to a particular action or structure of

the cardiovascular system. For example, saying that '*valves close to prevent blood from flowing upwards*' would be attributing a purpose to the closing of the valves.

3) *Elaborative explanation*: If participants produced explanations that inferred information from the animation, without assigning it a specific goal or purpose, in an elaborated way it was coded in this category. For example, the sentence '*blood in the muscle is oxygenated*' would be placed in this category.
4) *Monitoring statements*: These statements indicated whether participants did or did not understand the information presented in the animation and reflected checks on understanding, confusion, or questions about the learning material. For example, utterances such as '*I do not understand how the electrical system works*' or '*Okay, now I see why blood is traveling to the muscle*' are assigned to this category.
5) *Inference errors*: If participants made a self-explanation that reflected incorrectly inferred knowledge, it was referred to a false self-explanation. Ambiguous or partially correct inferences were not counted as errors. For example, the sentence '*Blood entering the muscles takes up oxygen, and then flows back into the right side of the heart*' was coded within this category because the purpose of the blood flow towards the muscles is inferred incorrectly.

Results

For all statistical tests, a significance level of .05 was applied. For any post-hoc analyses, we used analysis of variance (ANOVA). Effect sizes are expressed in terms of partial eta squared (partial η^2).

Learning outcomes

Table 1 shows the mean scores and standard deviations on the dependent measures for all conditions. A MANOVA on the learning performances of the retention test, the inference test, and the transfer test with the between-participants factors cueing (yes vs. no) and instructional strategy (self-explaining vs. instructional explanation) revealed a significant main effect for cueing (Wilks' lambda = 0.62, F (3,67) = 13.51, $p < .05$, partial η^2 = .377), and instructional strategy (Wilks' lambda = 0.89, F (3,67) = 2.77, $p < .05$, partial η^2 = .110). However, the interaction-effect between cueing and instructional strategy was not significant (Wilks' lambda = 0.95, F (3,67) = 1.09, $p > .05$). To clarify the MANOVA main effects, separate analyses of variance (ANOVA) with the factors cueing (yes vs. no) and instructional strategy (self-explaining vs. instructional explanation) were conducted for the performances on the retention test, the inference test, and the transfer test. The ANOVA for performance on the retention test revealed a main effect of cueing (F (1,69) = 10.67, MSE = 15.05, $p < .05$, partial η^2 = .134), indicating a higher number of correctly answered retention questions in the cued conditions (M = 18.32, SD = 3.97) than in the uncued

Table 1 *Means (and standard deviations) on the dependent measures as a function of condition*

	Self-explaining				Instructional explanation			
	Cued		Uncued		Cued		Uncued	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Learning Outcomes								
Retention test (0-26)	18.89	2.78	14.53	3.92	17.79	4.86	16.21	3.61
Inference test (0-23)	15.06	2.58	8.76	4.58	15.84	3.98	12.11	3.91
Transfer test (0-21)	7.89	3.07	4.59	2.76	8.37	3.27	5.11	2.08
Mental effort (ME)								
ME Animation (1-9)	4.83	1.89	5.29	1.83	4.32	1.49	4.95	2.04
ME Retention test (1-9)	5.72	1.67	6.82	1.42	5.58	1.77	6.58	1.98
ME Inference test (1-9)	5.72	1.56	5.94	1.20	5.05	1.93	6.21	2.04
ME Transfer test (1-9)	5.56	1.62	6.29	1.31	5.42	1.77	6.47	2.12

conditions (*M* = 15.42, *SD* = 3.81). However, no significant main effect for instructional strategy was found (F (1,69) < 1, *ns*).

For performance on the inference test, the ANOVA results showed a significant main effect for cueing (F (1,69) = 31.33, *MSE* = 14.61, p < .05, partial η^2 = .312), indicating a higher number of correct inferences on the inference test for the cued conditions (*M* = 15.46, *SD* = 3.35) than for the uncued conditions (*M* = 10.53, *SD* = 4.51). In addition, there was a significant effect of instructional strategy (F (1,69) = 5.31, *MSE* = 14.61, p < .05, partial η^2 = .071), with the instructional explanation conditions (*M* = 13.97, *SD* = 4.33) providing significantly more correct inferences on the inference test than the self-explaining conditions (*M* =13.03, *SD* = 4.65).

Concerning the performance on the transfer test, the ANOVA showed a significant effect of cueing, with the cued conditions (*M* = 8.14, *SD* = 3.14) scoring significantly higher than the uncued conditions (*M* = 4.86, *SD* = 2.40) (F (1,69) = 24.51, *MSE* = 8.00, p < .05, partial η^2 = .262). Furthermore, there was no significant effect of instructional strategy (F (1,69) < 1, *ns*).

In sum, the two cueing conditions obtained significantly higher scores on all three performance measures. The effect of instructional strategy, however, was restricted to an increased number of correct inferences for the instructional explanation condition on the inference test. Further, the absence of any significant interaction suggests that cueing was equally effective for the self-explaining condition and the instructional explanation condition. A MANOVA on the mental effort measures with cueing (yes vs. no) and instructional strategy (self-explaining vs. instructional explanation) as the between-participants factors revealed no significant differences on either cueing (Wilks' lambda = 0.90, F (4,66) = 1.80, p > .05) or instructional strategy (Wilks' lambda = 0.95, F < 1, *ns*), nor a significant interaction between cueing and instructional strategy was observed (Wilks' lambda = 0.93, F (4,66) = 1.22, p > .05).

Self-explanations during learning

To examine whether cueing influenced the self-explanation activity and to what extent studying a cued animation fostered different types of self-explanations, the self-explanation protocols of participants in the two self-explaining conditions were analyzed according to the coding scheme described above. In addition, we also examined how many of the 23 inferences that could be extracted from the animation (and which were tested in the inference test) were generated in order to determine the completeness and correctness of the generated inferences of the verbal protocols. For this purpose, the scores of the goal-directed and the elaborative self-explanations were added together to reflect the total number of inferences. Two independent raters that were unaware of experimental condition scored a randomly selected sample of approximately 20% of the verbal protocol data. To estimate the interrater reliability, we calculated Cohen's Kappa (k) on the pairs of scores in this subset. The results revealed a sufficient interrater agreement (k = 0.79), and therefore one of the two raters scored the remaining protocols.

Table 2 shows the mean number of each type of self-explanation and their standard deviations for both self-explanation conditions. The influence of cueing on the verbalizations and the number of each type of self-explanation was analyzed by a MANOVA with cueing as the between-participants factor and paraphrases, goal-directed self-explanations, elaborative self-explanations, monitoring statements, incorrect self-explanations, number of words, and number of self-explanation prompts as dependent variables. Because no participant made any positive monitoring statements, the monitoring statements only contained negative utterances.

The MANOVA showed that cueing significantly influenced the learners' self-explanation activity (Wilks' lambda = 0.36, F (7,27) = 7.01, $p < .05$). Although participants in the cued self-explanation condition did not receive more self-explanation prompts from the experimenter (F (1,33) = 1.82, MSE = 6.92, $p > .05$), and did not use significantly more words in their verbal protocols (F (1,33) = 0.41, MSE = 11045.80, $p > .05$) than the uncued self-explanation condition, significant differences were observed in the types of self-explanations that were generated in each of the two conditions (see Table 2). Participants in the cued self-explanation condition generated significantly more goal-directed self-explanations (F (1,33) = 18.58, MSE = 2.85, $p < .05$, partial $\eta^2 = .360$) and elaborative self-explanations (F (1,33) = 9.98, MSE = 9.83, $p < .05$, partial $\eta^2 = .232$) than participants in the uncued self-explanation condition. Furthermore, participants who self-explained with cues in the animation generated fewer monitoring statements (F (1,33) = 4.33, MSE = 2.05, $p < .05$, partial $\eta^2 = .166$) than participants who self-explained during the animation without cues. There was neither a significant effect of cueing on the generation of paraphrases (F (1,33) = 0.00, MSE = 51.38, $p > .05$) nor on the generation of incorrect self-explanations (F (1,33) = 0.73, MSE = 3.11, $p > .05$).

If we take a look at the completeness of the generated inferences, it becomes clear that the cued self-explanation condition has generated an average number of 11.23 (SD = 2.97) correct self-explanations or inferences whereas the uncued self-explanation condition has generated on average 5.42 (1.59) inferences. So, the total number of inferences that are derived from the animation through self-explaining appears to be at best less than half of the 23 inferences that the learners could infer from the animation or have received in the instructional explanation condition. Nevertheless, as Table 2 indicates, only a few incorrect inferences were generated. Thus, although self-explaining may lead to the generation of a number of correct inferences, the number of inferences that are generated is far from complete.

Table 2 *Mean number (and standard deviations) of type of self-explanations for the cued and uncued conditions*

	Self-explaining			
	Cued		Uncued	
	M	*SD*	*M*	*SD*
General				
Word count	460.61	102.91	437.77	107.38
Self-explanation prompts	10.61	3.27	9.41	1.70
Statements				
Paraphrases	21.28	5.67	21.35	8.48
Inferences (total)	11.23	2.97	5.42	1.59
Goal-directed self-explanation	4.17	1.95	1.71	1.36
Elaborative self-explanation	7.06	3.99	3.71	1.82
Monitoring	1.11	1.37	2.12	1.50
Incorrect self-explanation	.67	1.24	1.18	2.19

Discussion

The present study examined whether learning from an animation about the cardiovascular system with explanations was most effective if the explanations are generated through self-explaining or by providing learners instructional explanations as a narration and whether or not the explanations should be supported by visual cues in the animation. The results showed that a cued animation with explanations was more effective at improving learners' conceptual understanding of the animation than an uncued animation with explanations. This finding is in line with our hypothesized main effect of cueing and partially supports the results of a study by De Koning et al. (submitted), who demonstrated increased performance on an inference and transfer test when self-explaining with a cued compared to an uncued animation. Moreover, it provides evidence that self-explaining with a cued animation can not only improve understanding of the cardiovascular system for secondary school students (see De Koning et al., submitted) but also for university students. The present findings extend the De Koning et al. (submitted) study by showing that, analogous to the self-explanation results, the learners who received instructional explanations accompanying a cued animation also developed a more thorough conceptual understanding than learners who received instructional explanations accompanying an animation without cues. Our results thus seem to suggest that cues may also play an important role in improving learning from an animation with instructional explanations. However, a comprehensive account of how cues might influence learning from animations with text has still to be developed.

Furthermore, the results showed no significant interaction effects between self-explaining and receiving instructional explanations with a cued animation. However, learners who received instructional explanations while studying the animation had higher learning performances on the inference test than learners who generated self-explanations during their inspection of the animation. This does not seem surprising, as the learners in the instructional explanation conditions could improve their performance on the inference test by simply listening to the narration that explicitly provided all correct functional relations of the cardiovascular system, and therefore only required learners to reproduce the information contained in the narration to correctly answer the inference test items. In addition, learners in the self-explanation conditions were only able to generate less than half of the number of these inferences, indicating that self-explainers were unable to extract the required functional knowledge from the animation. However, despite that the narration group has received all 23 correct inferences via the narration whereas the self-explanation group had only generated approximately 11 inferences in the self-explanation protocols during learning, it is striking that in the cued conditions the scores on the inference test for the narration groups and the self-explanation groups are not far apart. Moreover, in contrast to our predictions, the scores on the transfer test, which assessed the quality of the learners' mental representation of the cardiovascular system, did not differ between the self-explanation conditions and the instructional explanation conditions. So, despite the incompleteness of self-explaining, learners who self-explained seemed well able to generate a reasonable number of inferences and to perform almost as good as the narration groups (especially the cued condition) on the transfer test. Therefore, it might be suggested that providing correct functional information to learners via narration accompanying an animation does not guarantee that learners construct far more accurate mental representations from dynamic systems. This is in line with research on learning from worked-out examples and multiple representations showing that instructional explanations may not necessarily encourage learners to develop more accurate mental representations (Schworm & Renkl, 2006; for an overview see Wittwer & Renkl, 2008).

The present findings suggest that two very different instructional strategies, namely actively generating self-explanations and receiving instructional explanations, can yield similar conceptual understanding and mental representations of dynamic systems via cued animations. Although it is yet unresolved whether the same or different explanations underlie the processing in both strategies, cognitive load theorists (Ayres & Paas, 2007) would argue that cueing has led to a more effective use of working memory resources by reducing irrelevant processing and therefore may have created a situation in which working memory resources can be used for productive learning activities (also see Gerjets et al., 2006). However, more research is needed that tests explanations concerning the involvement of different types of cognitive load more directly as well as other possible influencing factors, because the present results do not allow us to determine the relative contribution of each type of cognitive load to learning and does not provide insight into the actual cognitive processes that occur during learning. For example, it may be investigated whether the generative nature of self-explaining is the crucial factor that may allow learners to keep up with learners who construct mental representations from narrated animations and whether this may lead to knowledge that may be retained for longer periods of time, which might be investigated by taking the learning outcome measures at different time intervals after studying an animation.

With respect to the implications for instructional design several interesting conclusions can be drawn from the present findings. First, encouraging learners to generate explanations for themselves or providing learners instructional explanations during an animation may not be enough to improve learning. Rather, effective learning is more likely to occur if learners do not have to search for information due to cues, which allows them to directly concentrate on understanding the functional relations and the underlying principles (cf. Renkl & Atkinson, 2007). Second, irrespective of cueing, instructional explanations containing the crucial functional relations might improve learners' functional understanding of an animation. Third, prompting learners to self-explain during a cued animation can be as effective for building a mental representation as providing instructional explanations accompanying a cued animation. One aspect that seems relevant for learners to deepen their understanding and to improve learning from instructional explanations and animations is that both representations are presented in such a way that the possibility of engaging in active cognitive processing is increased (also see Wittwer & Renkl, 2008). In addition, from a practical point of view providing instructional explanations accompanying an animation might be more structured, less intrusive, and easier to implement in real classroom situations than prompting learners to self-explain during an animation and therefore may be preferred in collective learning scenario's.

The present findings and the practical recommendations that follow from it need to be interpreted with caution as long as they have not been tested for its generalizeability and robustness in other studies. In the present study, the same spotlight-cues were used to reduce the size of the total area of the visual display that should be explored in the self-explanation condition and the instructional explanation condition. However, despite the need to guide attention in both conditions, the function of cueing in the self-explanation condition was to emphasize essential parts of the animation, whereas the function of cueing in the instructional explanation condition was to facilitate the integration of different representations (De Koning et al., 2009). Focusing attention on a complete subsystem of the cardiovascular system rather than on more specific elements within the (sub)system may have lacked specificity and consequently may have hindered the integration process and the subsequent construction of an integrated mental representation in the instructional explanation condition. Future studies should investigate whether cueing approaches that provide more specific guidance in relating elements between different representations can further enhance learning from narrated animations. In addition, it may be desirable to examine whether the findings obtained in this study may be generalized to other types of cueing (e.g., arrows) than spotlight-cueing. Moreover, further research is required to examine whether the present findings can be obtained in longer educational tasks, with different types of animations (e.g., non-cyclical), in more educationally valid research settings (i.e., regular classroom), and when interactivity is provided that allows learners to adjust the presentation of the animation to their cognitive processing abilities.

Another aspect that requires further investigation is whether providing instructional explanations together with self-explanations, for example by using a narration for providing feedback after the self-explanation activity, may further improve learning from animations. Roy and Chi (2005) have proposed that engaging in self-explanatory activities should be particularly helpful for integrating information from multiple representations (e.g., animation and narrated instructional explanation). In learning from worked-out examples it has already been shown that novices may benefit from instructional explanations in order to deepen their understanding during self-explanation activities (Renkl, 2002). It would be interesting to investigate whether similar effects could be obtained with learning from (cued) animations accompanied by narrations.

In sum, the results of this study suggest that in order to foster meaningful learning from animations with learner-generated (i.e., self-explaining) or externally-generated explanations (i.e., narration) cues are required that guide learners' attention to relevant aspects within and/or between representations which allow them to directly focus their cognitive activities on understanding the functional relations of the presented information. Moreover, the present findings indicate that studying a cued animation with explanations by generating self-explanations or by receiving instructional explanation as a narration did not lead to different learning outcomes. This suggests that in a cued animation the provision of correct and accurate information via narrations may not pay off against the flexibility and generative nature of self-explaining.

Chapter

7

Towards a framework for attention cueing in instructional animations: Guidelines for research and design[6]

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Abstract

This paper examines the transferability of successful cueing approaches from text and static visualization research to animations. Theories of visual attention and learning as well as empirical evidence for the instructional effectiveness of attention cueing are reviewed and, based on Mayer's theory of multimedia learning, a framework was developed for classifying three functions for cueing: 1) selection – cues guide attention to specific locations, 2) organization – cues emphasize structure, 3) integration – cues explicate relations between and within elements. The framework was used to structure the discussion of studies on cueing in animations. It is concluded that attentional cues may facilitate the selection of information in animations and sometimes improve learning, whereas organizational and relational cueing requires more consideration on how to enhance understanding. Consequently, it is suggested to develop cues that work in animations rather than borrowing effective cues from static representations. Guidelines for future research on attention cueing in animations are presented.

Recent advances in software and computer technology enable designers of computer-based instruction to use dynamic visualizations, such as animation and video, to help learners remember complex dynamic systems and, ultimately, understand the materials (Lowe, 2004). At present, the majority of animations present information in close correspondence with the referential situation, without highlighting the information or providing cues to help learners process the material. However, manipulating the visuospatial characteristics of animations may make them more effective, just as manipulating these aspects in static representations (e.g., enlarging or highlighting information in text and pictures) improves learning (Tversky, Heiser, Lozano, MacKenzie, & Morrison, 2008). We refer to the manipulation of visuospatial characteristics of instructional materials in order to help learners in selecting relevant information, and organizing and integrating the information into a coherent representation as 'cueing', which is similar to 'signaling' that has its origins in text processing research and is recently applied to learning from illustrations (Mautone & Mayer, 2001; Meyer, 1975). Cueing is intended to draw learners' attention to essential elements of the (visual) representation, for instance by increasing the luminance of specific objects in a visual display (e.g., De Koning, Tabbers, Rikers, & Paas, 2007) or by changing a word's font style to boldface in a text (e.g., Mautone & Mayer, 2001). It is important to note that cues do not provide new information or change the content of the instructional materials (Lorch, 1989). This paper examines whether cueing approaches that have been successfully used in static representations (i.e., text and visualization) can be effectively transferred to animations in order to improve learning.

Learning from complex animations

In recent years, learning from animations has received a considerable amount of attention from educational researchers (Ploetzner & Lowe, 2004). Schnotz and Lowe (2008) define an animation as a dynamic visual representation where the information about temporal change is contained in the difference of object properties between successive frames. Intuitively, animations seem more effective at illustrating the configuration and behavior of complex systems that involve changes of objects and their positions over time than static visualizations. In addition, animations appear to be a natural for conveying concepts of change (Tversky, Morrison, & Bétrancourt, 2002) and due to their ability to depict the temporal changes in the operation of complex dynamic systems explicitly, can provide a real-time external representation that can be directly mapped onto the referential situation (Gibson, 1979).

Although a review by Tversky et al. (2002) found little evidence that animations were superior to static visualizations (see also Mayer, Hegarty, Mayer, & Campbell, 2005), a meta-analysis by Höffler and Leutner (2007) indicated that under some conditions animations may produce better learning than static visualizations. According to Tversky et al. (2002), failures to find improved learning from animations might result from the fact that animations are often 'too complex or too fast to be accurately perceived' (p. 247). Several studies have shown that learning from animations is hindered if presentation speed is too high (e.g., Meyer, Rasch, & Schnotz, in press), or if attention is distracted by irrelevant movements in the animation (e.g., Lowe, 1999). Accordingly, several researchers have argued that animations place excessive demands on the learners' cognitive system due to the transitory nature of the presented information and the simultaneous depiction of multiple changes (Ayres & Paas, 2007a; Lowe, 1999, 2003; Tversky et al., 2002).

First, the transient nature of animations requires learners to process information that is shown very briefly and disappears before it can be selected for further processing, unless they leave some kind of trace in which key information is kept available (Marcus, KhengJoo, Beng-Fei, & Ayres, 2006; Paas, Van Gerven, & Wouters, 2007). When viewing an animation, learners not only need to integrate new information with existing knowledge that is stored in long-term memory (LTM), but also with previously presented information that has to be kept active in working memory (WM). Therefore, the transient nature of animations may cause learners to split their visual attention over different elements that are dispersed over time. This may consequently challenge the resource limitations of the learner's WM (Miller, 1956) and hinder learning (Ayres & Paas, 2007a; Paas, Renkl, & Sweller, 2003).

Second, trying to understand an animation requires learners to simultaneously attend to many elements that move from one location to the other and might change with respect to different perceptual attributes (e.g., color, form, orientation). There is a considerable amount of evidence in the perception literature that such dynamic changes are very effective at capturing attention when searching for specific information, even when they are task-irrelevant (e.g., Franconeri & Simons, 2003; Treisman & Gormican, 1988). Moreover, Hillstrom and Chai (2006) even suggested that dynamic aspects, such as movements or a sudden appearance of an object, are perhaps the most effective object characteristics for capturing attention in a visual display. Therefore, it is not surprising that learners often have difficulties in focusing their attention on essential information in an animation, as objects that have high perceptual salience due to their movements easily distract them. This might especially hinder learning in situations where the thematically relevant aspects are not the most salient in an animation (Lowe, 1999, 2003).

Although the problems resulting from the transient character of animations and the simultaneous presentation of multiple moving elements may occur independently, they will most likely interact. For example, focusing attention seems especially relevant if the information is only briefly available and there is no opportunity to re-inspect it. Therefore, it is crucial that designers of animations have instructional tools at their disposal to guide the learners' attention at the right moment to the right information in the display (Schnotz & Lowe, 2008).

It is well-established that cueing may help learners extract and process the essential information from static information (Tversky et al., 2008). However, it is possible that cues found to be effective in static instruction are less effective when used with animations. Especially, the transiency in animations provides an extra challenge to the use of cues. Because in animations there is only limited time in which relevant information can receive attention before it disappears and there is a possibility of being distracted by irrelevant movements, guiding attention becomes more difficult because learners should not only be aware of *which* elements are being cued but also *when* they are cued. Therefore, cues such as arrows may lack precision required for effective attentional guidance to small and fast changes. Moreover, cueing by changing the properties of a visual representation (e.g., color change) has the advantage of not adding extra elements to the display, but due to the additional demands in animations it may be less clear for learners or they may not have enough time to find out that this manipulation is a cue that is not part of the content of the animation. Consequently, cueing may increase the possibility for causal misinterpretations and increase learning demands to the representation even further by requiring learners not only to identify and process the structure and meaning of the animation but also that of the cues in a limited amount of time.

In the remainder of this article, findings from research on visual attention and attention capturing mechanisms are discussed to specify the perceptual processes involved in cueing. Next, cognitive load theory is introduced as a theoretical basis for the cognitive aspects of cueing. Then, a framework is proposed for distinct functions of cueing based on the cognitive theory of multimedia learning (Mayer, 2001) that is supported by research on learning from static representations. Next, existing research on the effectiveness of cueing in animations will be discussed. Then, based on our framework of cueing we will present recommendations for directing research dealing with cueing in instructional animations and guidelines for instructional design.

Theoretical accounts of the effect of cueing on perceptual and cognitive processing

Several theoretical models are currently used to describe cognitive processing with regard to learning from animations and multimedia (e.g., Mayer, 2001; Sweller, 1988). However, these models are less explicit about the perceptual processes involved in the initial stages of distinguishing between relevant and irrelevant information. Therefore, to provide a comprehensive account of the effect of cueing in animations, models of visual attention are used to give an account of the perceptual processes involved in cueing in animations and cognitive load theory and Mayer's theory of multimedia learning are used to provide insight into the cognitive processes underlying cueing in animations. Each of the approaches will be discussed in turn.

The effect of cueing on perceptual processes

Human visual perception is extremely selective. Learners can focus their visual attention only on a small amount of elements of a visual display at once and only a small portion of that information can be subsequently processed in WM (Baddeley, 1992). The elements learners will look at are determined by several factors such as the elements' prominence and their level of detail (Winn, 1993). Carefully identifying the characteristics that contribute to the perceptibility of information allows the identification of the properties that potentially capture attention in animations and to predict the conditions under which cueing in animations may be effective.

Schnotz and Lowe (2008) have distinguished two features that influence the perceptibility of different elements of animations: visuospatial contrast and dynamic contrast. For visuospatial contrast an element stands out against surrounding elements because it has other distinctive visual features, such as a different size or unique color. A dynamic contrast occurs if an element's movements and temporal changes establish a figure-ground distinction that in turn captures learners' attention. Numerous studies on visual search and cueing paradigms in visual attention research have offered related suggestions about what object features might capture attention and facilitate the identification of objects or events.

First, there are objects that have distinctive features and therefore differ substantially with respect to the visuospatial distribution of object properties (e.g., color, form). In different visual search paradigms, the unique characteristics of an object that make an object visually more salient by establishing a contrast on one or more perceptual attributes speeds up the identification of target objects irrespective of the number of surrounding objects (Treisman & Gelade, 1980; Treisman & Gormican, 1988). For example, finding a green digit among red ones reduces the time taken to detect the target, because the unique color of the target causes it to be more salient and to pop-out from the background of red distracters. This pattern has been found in particular if the object is relevant for the task (Yantis & Egeth, 1999), but even persists if attending to the object that pops-out is known to be irrelevant and disadvantageous to the performance of the task (e.g., Pashler, 1988; Theeuwes, 1991, 1992). Especially unique colors (e.g., Nagy & Winterbottom, 2000; Turatto & Galfano, 2000, 2001; Turatto, Galfano, Gardini, & Mascetti, 2004) and luminance contrasts (Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001) seem very effective at capturing attention.

Second, a number of researchers have emphasized the importance of temporal discontinuities in object properties present in a visual scene, that is, abrupt onsets or changes in objects over time ('transients') to capture visual attention, especially when they occur rapidly. In several studies, Jonides and Yantis (1988; Jonides, 1981; Yantis & Jonides, 1984) have demonstrated that onset transients effectively capture attention. Furthermore, Miller (1989) showed that attention is not only controlled by sudden onsets, but that attention is attracted by all sudden changes in a visual scene. Indeed, in line with the dynamic default hypothesis (Franconeri & Simons, 2003), which states that all dynamic events garner attentional priority, different types of motion, such as the start of movement (e.g., Abrams & Christ, 2003), moving, looming, and disoccluding objects (Franconeri & Simons, 2003) may draw attention and cause people to fixate on the target object (Godijn & Theeuwes, 2002). However, it is important to note that motion per se does not attract attention. Attentional capture only occurs when movements segment an object from its background (Hillstrom & Yantis, 1994).

The findings suggest that bright colors and coarse movements within animations may have their own intrinsic cueing effects and hence have the potential to capture learners' attention almost automatically (i.e., inherent content cues). However, cues to enhance perceptual and cognitive processing are not conceptualized as part of the content. Rather, they are considered to be artificially added to animations (e.g., arrows) with the intention of (re)directing attention to aspects of the display that deserve the learners' attention (i.e., instructional cues). For this purpose, manipulating attention-gaining features like colors and movements might be effective cues for minimizing the salience of irrelevant elements (e.g., dimming irrelevant bright colors) and focusing on thematically relevant information (e.g., flashing essential parts).

In short, a large amount of evidence from selective visual attention research has shown that an object may automatically capture attention or stand out more easily if 1) the object differs from other objects on at least a single attribute such as color, or if 2) objects move from one location to another, irrespective of whether the movements foster or hinder the learning process. Because both of these aspects are likely to be present in complex animations, the design of cues for animations should be based on these same properties to effectively redirect learners' attention to relevant elements.

The effect of cueing on cognitive processes

Several instructional design theories, such as Mayer's cognitive theory of multimedia learning (Mayer, 1997, 2001) and Sweller's Cognitive load theory (Sweller, 1988, 1999) provide an explanation for the effect of cueing in terms of the limitations of human information processing resources. A central notion in both theories is that the cognitive system consists of a WM that is relatively limited both in capacity and duration and a LTM that is assumed to have an unlimited capacity to store new information (Cowan, 2001; Miller, 1956). According to these theories, directing learners' available resources to the learning process itself rather than to irrelevant features of instructional materials is therefore central to designing instruction.

According to Mayer (1992), meaningful learning requires the learner to select relevant information, organize that information into a coherent representation, and integrate this representation into existing knowledge. This is only possible if the elements that have to be mentally combined are simultaneously active in WM (Mayer, 2001). WM thus plays an essential role because this is considered the structure, where the selection, organization, and integration processes take place. However, sometimes these processes may be cognitively demanding at the expense of mental resources that could otherwise be allocated to understanding the content. According to cognitive load theory three types of cognitive load can be identified (Paas et al., 2003): 1) intrinsic cognitive load that is inherent to the task, and consists of interacting information elements that must be processed simultaneously in WM to understand the content; 2) extraneous cognitive load, which is imposed by processes that do not contribute to learning (e.g., searching a picture for referents mentioned in a text), and are evoked by the instructional design; 3) and germane cognitive load, which is imposed by processes that are effective for learning (e.g., integrating new information into already existing schemata), and is also evoked by the instructional design.

The construction of adequate and rich schemata may be especially challenging in learning from dynamic visualizations of specialized subject matter. Because of the amount and complexity of information learners have to process when studying animations, the selection of relevant elements, their organization, and the construction of links between textual and/or pictorial elements are likely to impose a high cognitive load. As cues focus the learners' attention on the most relevant information, visual search is reduced and less visuospatial resources are required to control the execution of eye-movements. Thereby, cueing reduces extraneous cognitive load associated with locating relevant information. This frees up mental resources that can be used for cognitive activities that are directly relevant for schema construction (e.g., integration of information).

Evidence that cued instruction requires less cognitive resources comes from a study on text processing by Britton, Glynn, Meyer, and Penland (1982). In their study, students read a cued or an uncued text while at the same time their reaction times to a secondary task were measured as a measure of cognitive load. Results indicated that texts containing cues about relevant concepts and their relations required less cognitive resources to process than texts without such cues. Moreover, in a study comparing groups who studied cued or uncued texts, Loman and Mayer (1983) showed that the reduction in cognitive load in the cued condition allowed learners to construct a deeper representation of the content, as indicated by better retention and transfer performances.

Research on multimedia learning that used a subjective rating scale as an indicator of experienced cognitive load (Paas, 1992; Paas & van Merriënboer, 1993, 1994; Paas et al., 2003) provides some evidence for the effects of cueing on cognitive load. In a study by Kalyuga, Chandler, and Sweller (1999), color-coding cues that linked on-screen text with corresponding parts in an illustration reduced cognitive load and improved learning performance (see also Jamet, Gavota, & Quarieau, 2008), suggesting that cues can effectively increase WM resources available for learning. In contrast, Keller, Gerjets, Scheiter, and Garsoffky (2006) and Tabbers, Martens, and van Merriënboer (2004) could not find a reduction of cognitive load but did find better learning performance.

In summary, effects of cueing on cognitive processing are primarily explained by reduced visual search and the unnecessary load associated with locating relevant information, which frees up WM resources for genuine learning activities. In both text and visualization research evidence has been found to support this explanation with some studies demonstrating a reduction in cognitive load whereas other studies have reported better learning performance without reduced cognitive load.

A framework for classifying different functions of cueing

So far, it was stressed that both perceptual and cognitive factors have to be taken into account when providing a theoretical explanation for cueing. However, the extent to which cues include perceptual and/or cognitive aspects may depend on the function(s) served by cues. Therefore, we propose a framework for different functions of cueing. The framework is grounded in Mayer's cognitive theory of multimedia learning as the theory's distinction between the processes of selection, organization, and integration of new information provides a solid basis for identifying three main functions of cueing that might be related to distinct perceptual and cognitive effects: 1) guiding learners' attention to facilitate the selection and extraction of essential information, 2) emphasizing the major topics of instruction and their organization, 3) making the relations between elements more salient to foster their integration. The rich collection of prior research on cueing that has examined the effects cues have on understanding text and/or illustrations is used to provide empirical support for the proposed functions (see the first four columns of Table 1). Each of the functions will now be discussed in more detail.

1. Guiding attention to essential information

A crucial part of constructing a coherent representation from instructions is the learners' ability to extract main ideas or concepts that subsequently can serve as the basis for further processing. To what extent learners succeed in this task largely depends on the proper allocation of attention (Gaddy, Sung, & Van den Broek, 2001). In general, learners frequently do not possess adequate knowledge to discriminate relevant from irrelevant information and, therefore, may be at risk of focusing on non-essential information or draw inaccurate conclusions (Bromage & Mayer, 1981; Graesser, 1981). For example, learners who are unfamiliar with the subject-matter may find it difficult to identify the main themes in a text or select the relevant elements in a picture. Instructional designers can guide the process of attention allocation by using cueing to emphasize content that requires intentional processing. The first function of cueing is thus to emphasize particular information intended to indicate the relevance of the cued content. This kind of cueing is highly specific and unambiguous with respect to the information that is cued (Lorch, 1989). For example, color variations in illustrations or underlining words in a text are means to stress the importance of cued information. Numerous studies on text comprehension that have used memory performance (i.e., recall) as an indicator of attentional processing, have consistently shown that cues improve the recall of the content they emphasize (Cashen & Leicht, 1970; Dee-Lucas & DiVesta, 1980; Fowler & Barker, 1974; Hartley & Trueman, 1985; Lorch & Lorch, 1996). Memory for uncued content is unaffected (Foster, 1979; Golding & Fowler, 1992), inhibited (Glynn & DiVesta, 1979), or sometimes even enhanced (Cashen & Leicht, 1970). These findings suggest that emphasizing particular content may guide learners' attention to essential information but does not necessarily reduce attention for uncued information. In addition, Lorch, Lorch, and Kluzewitz (1995) and Lorch and Chen (1986) have demonstrated that cues slow down the reading times for text processing, which provides direct evidence that effects of cueing on memory are mediated by processes of attention.

Furthermore, studies examining the influence of emphasizing specific content in illustration-based problem-solving tasks support the notion that cueing can guide attention and subsequent cognitive processing. Using Duncker's (1945) radiation problem, Thomas and Lleras (2007) and Grant and Spivey (2003) demonstrated that by redirecting the learners' attention to critical elements of the problem using for example color highlights led to more correct problem-solutions than studying the same diagrams without such cues. This is in line with Park and Hopkins' (2003) recommendation to use perceptual features (e.g., color,

Table 1 *Summary of the functions of cueing and their effects on perceptual and cognitive processes in static and dynamic representations*

Function of cueing	Type of process	Level of processing	Effects of cues on perceptual and cognitive processing in *static* representations	Effects of cues on perceptual and cognitive processing in *dynamic* representations
Guiding attention	Selection	Mainly perceptual	More attention to cued than uncued information	More attention to cued than uncued information
			Better retention of cued information	Sometimes better retention and transfer of cued information but often no effects
			Improved problem-solving performance	-
Emphasizing organization	Organization	Cognitive	Better retention of cued information Faster identification of organizational structure	No effect on retention/transfer of cued information
			Internal representation organized according to the emphasized organizing structure	-
Highlighting relations (within/between representations)	Integration	Cognitive	Better retention of cued information	No effect on retention of cued information
			Higher performance on transfer task	No effect on transfer test performance
			Increased number of causal inferences	-

Note: ' – ' indicates that the effect of cueing on this type of processing was not investigated motion) to guide learners' attention to critical information during (visual) instruction. A similar argument was made by Wetzel, Radtke, and Stern (1994) for improving the learning effectiveness of video-based instruction.

In short, the empirical evidence on cueing in text and/or illustrations clearly demonstrates that perceptually emphasizing information facilitates the selection of relevant elements, and subsequently improves learners' retention of cued content and improves problem-solving.

2. Emphasizing the organization of instruction

The global organization of instructions is usually made up of individual parts and subparts that together constitute a hierarchical structure (Schnotz & Lowe, 2008). Therefore, identifying the individual elements and combining them into a coherent structure are essential aspects of the comprehension process. Representing the organizational structure of a text, for example, requires learners to identify individual topics, topic shifts, and determine how topics are related (Lorch, Lorch, & Matthews, 1985). Indeed, according to Gernsbacher's structure-building framework (Gernsbacher, Hargreaves, & Beeman, 1989; Gernsbacher, Vamer, & Faust, 1990), at the end of a section learners may engage in processing to integrate a new topic with previous related topics in the text, or treat the new topic as independent of previous text content. Consequently, at each transition between topics the overall organizational structure will be updated (Lorch et al., 1985). However, discerning the topic structure from text passages often fails if learners are not adequately supported with cues that emphasize the text's global topic structure (Loman & Mayer, 1983; Lorch & Lorch, 1995; Rickards, Fajen, Sullivan, & Gillespie, 1997). Therefore, a second function of cueing is to emphasize the organization of instructions to help learners to accurately represent the structure of the presented information.

A variety of cueing techniques, such as outlines and headings, is available to assist learners in identifying the main topics of texts and their organization. There is abundant evidence that organizational cues facilitate text processing, as demonstrated by studies reporting shorter reading times for topic-introducing sentences when an outline of the topical structure of a text is provided or when the topic shifts are cued by the preceding text (Lorch et al., 1985; Lorch, Lorch, Gretter, & Horn, 1987). In addition, organizational cues improve the retention for text topics and their organization (Loman & Mayer, 1983; Lorch & Lorch, 1985, 1995, 1996; Lorch, Lorch, & Inman, 1993; Meyer, Brandt, & Bluth, 1980), although this may occur at the cost of remembering deemphasized content (Mayer, Dyck, & Cook, 1984). Specifically, cues that emphasize the topic structure alter the organization of text in memory, without necessarily influencing the amount of content recalled. That is, the organization of content in recall closely resembles the structure of the text (Lorch & Lorch, 1985, 1995, 1996; Lorch et al., 1993). However, organizational cues are only effective in altering the organization of content in memory if the instructions are complex and do not involve a well defined structure or contain many topics (Lorch, 1989; Lorch & Lorch, 1996; Meyer, 1975).

Despite a large amount of studies investigating the effects of organizational cues on text processing, very little research has examined the organizational function of cueing in visualizations. Visualizations may effectively represent the structure of non-moving phenomena by showing an object's (sub)parts and their spatial relations (Tversky et al., 2002). Graph comprehension research indicates that, depending on how information is structured and hence what information is emphasized in a graph's perceptual organization, different elements are extracted for constructing a mental representation (Shah, Mayer, & Hegarty, 1999). Therefore, Shah et al. (1999) argued that representing graphical information in a way that makes important information (i.e., trends, associations) more salient and requires less mental computations facilitates comprehension in terms of retention and transfer performance. However, the organizational structure may be difficult to depict accurately in a static visualization when temporal dimensions are involved such as when depicting a complex dynamic system (e.g., cardiovascular system). For example, so-called 'exploded diagrams' that show the components of a complex dynamic system slightly separated from their original location, often fail to provide a good overview of the sequence of assembly. Therefore, in their analysis of the characteristics of what constitutes good graphics, Tversky et al. (2008) concluded that to accurately identify the structure of dynamic events in static visualizations cueing devices such as numbers and arrows representing a sequence need to be included. Despite many examples of organizational cueing in static visualizations, the effectiveness of organizational cues on learning from static visualizations involving a temporal dimension has yet to be investigated systematically.

In short, research on the effects of cueing the organizational aspects of texts or illustrations shows that cues may facilitate the identification and the subsequent representation of the material's structural organization and improve retention performance. It should be noted, however, that most of this evidence is based on text processing research.

3. Integrating elements within and between representations into a functional model

For learners to build a coherent and integrated representation of the content of instructions, it is insufficient to merely attend to key elements and the structural features of the instruction (with or without the help of cues). Rather, several important processes such as making causal inferences and being aware of temporal dimensions of information are central to building a coherent and integrated functional representation (e.g., Kieras & Bovair, 1984). Because these cognitive processes are deeply constructive activities, they require considerable cognitive capacity and will only contribute to learning if the total cognitive resources are not exceeded.

It is important to make a distinction between cueing relevant concepts and the content's structural organization (Meyer, 1975), and cueing the (causal) relations between concepts (Mayer et al., 1984). Whereas organizational cues operate at a global level to point out the main topics of instruction, relational cues that indicate connections between related elements and are intended to foster the integration of these elements operate at a more local level.

Thus, the third function of cueing is to construct an integrated mental representation by guiding the process of attending to complex relations between elements. This function can be divided into two categories: 1) cueing to emphasize the relation between two elements within a single representation (e.g., text or picture) and 2) cueing to draw attention to connected elements in different representations (e.g., text and picture).

Relating elements in a single representation

It is common in expository texts or complex illustrations that elements having a relation with respect to content or function may be difficult to find and link because they are widely separated across the content (Lowe, 1989). Without any guidance emphasizing the important relations, learners may fail to integrate all information into a coherent representation because searching for related elements and trying to relate them may impose a high cognitive load. In fact, there is substantial evidence that using cues explicating the relations between elements in an expository text, such as cross-referencing words or phrases (e.g., 'Recall our earlier discussion of…'), helps to process the content more slowly and improves memory for cued content (Glover, Dinnel, Halpain, McKee, Corkill, & Wise, 1988). In addition, emphasizing the causal links in a description of a causal system with relational cues (e.g., 'because of this..') fosters the integration of information as indexed by improvements on transfer tasks (Loman & Mayer, 1983; Mayer et al., 1984; Mautone & Mayer, 2001). However, cueing does not always result in an integrated representation. For example, Harp and Mayer (1998) did not find beneficial effects of relational cueing sentences (e.g., 'Each of the steps are related, in that one step causes the next to occur') on transfer using a well structured text with simple relations. This suggests that cueing improves the integration process only if the content is ill-defined and relatively complex. In short, cueing the relations between concepts in a single representation when they are -perceptually- less clear or not easily found may facilitate schema construction processes.

Furthermore, sometimes, particularly in visualizations, information can only be depicted indirectly and therefore has to be inferred like information about function, the sequence of operations and their causal outcomes in visualizations (Tversky, 2001).

Previous research has shown that the process of inferring dynamic information from static pictures imposes a high extraneous load on the learner and causes errors (Hegarty, 1992). Therefore, graphical cues such as arrows and lines are often suggested to explicate causal relations that are unclear or too implicit in the presentation (Tversky et al., 2008; Tversky, Zacks, Lee, & Heiser, 2000). It is important to note that while similar graphical cues may be used for guiding attention to specific information, their purpose as a relational cue is to make a sequential or temporal relation more explicit instead of merely emphasizing a single location.

The few studies that have empirically investigated cues to explicate relations provide evidence that enriching a static illustration with graphical cues (i.e., arrows) cause learners to interpret the illustration functionally, as reflected by increased reports of functional inferences and use of verbs of motion and cause in their descriptions of the depicted content and improved understanding of the content (Heiser & Tversky, 2002, 2006; Schneider & Boucheix, 2008). Similarly, verbal cueing (e.g., 'With the help of the green dot imagine the direction in which gear A turns', see Boucheix & Guignard, 2005) focuses attention and encourages learners to infer information and improves the retention and comprehension of a system's operation (Boucheix, 2008; Boucheix & Guignard, 2005). This is especially true for learners with low spatial abilities (Schneider & Boucheix, 2008). Nevertheless, such cues do not necessarily result in extracting the causal inferences that underlie functional relations (Mautone & Mayer, 2007). In short, the majority of empirical evidence shows that functional relation cues that make implicit information (i.e., causal relations) within representations more explicit may improve learning.

Relating elements between representations

Another way of emphasizing relations concerns making learners aware of the relations between elements that are spatially distributed over different representations, such as in an illustrated text. When graphical information is accompanied by verbal explanations (written or spoken), learners must search through the graphical representation to establish links between elements in the verbal and graphical representations, and mentally integrate the two representations to form an accurate mental model (Johnson-Laird, 1983). Many interacting elements of information are involved in such search and tracing tasks, which may interfere with learning-related activities. Cognitive load theory suggests that learning may be facilitated by physically integrating the two sources of information to reduce the need for mental integration (Chandler & Sweller, 1991) or by presenting information in different modalities, that is, the combined use of visual and auditory channels (see Ginns, 2005 for a review on the modality effect). Nevertheless, in complex tasks involving many information elements learners still may be unable to find the visual referents and establish a link between corresponding elements in the verbal and nonverbal representations. Here, the function of cueing is to explicate such links in order to help learners in building an integrated mental representation.

Several different cueing techniques for pointing out crucial connections between representations in various studies, like flashing to connect related elements (Craig, Gholson, & Driscoll, 2002; Jeung et al., 1997), giving related elements the same color (Kalyuga et al., 1999), and orienting cues (i.e., gestures, gaze) as guides to related elements (Lusk & Atkinson, 2007), showed that cueing improves the retention for cued content and facilitates the application of learned information as reflected in better performances on problem-solving transfer tasks or reduced problem-solving time. However, positive effects of relational cues on transfer performance are not always found (Jamet et al., 2008; Tabbers et al., 2004), suggesting that effects of cueing on deep comprehension (i.e., transfer) are less consistent. This is consistent with findings of Mautone and Mayer (2007) who demonstrated that using color-coding and arrows to relate text and illustrations in order to improve graph comprehension only enhanced the number of relational statements but not of causal relations. In addition, cueing only improves retention and transfer performance if the visualization is very complex and can not be understood without cues that guide learners' processing (Jeung et al., 1997).

Furthermore, research on cueing in hypermedia also demonstrates that relational cues, such as connecting lines and textual hyperlinks are effective strategies for drawing the learners' attention to specific parts of a visual representation and to relate them to the corresponding textual information (Huk & Steinke, 2007; Seufert & Brünken, 2006). This indicates that the effects of relational cues on learning are not restricted to instructions that are presented in an easy to follow step-by-step fashion.

In short, the empirical findings provide support that several types of cueing that establish a relation between corresponding elements in different representations improve retention performance. However, the inconsistent results concerning transfer of learning suggest that emphasizing the relation between elements may not necessarily result in a more coherent and integrated representation. In addition, instructional materials seem to require a considerable level of complexity for cueing to be effective.

In conclusion, at least three distinct functions of cueing have been identified, which are supported by prior research on the effects of cues on learning from static instruction. Cues can be effective means for 1) guiding attention to specific locations, 2) organizing information, and 3) integrating individual elements into a coherent representation. Importantly, different types of cues may serve multiple or related functions. Specifically, organizational cues may emphasize several aspects of structure. Moreover, cues may have different functions depending on the medium in which they are used. For example, emphasizing information with color variations may be done in text to stress the importance of that part of the content, whereas in multimedia learning it may be used for making learners aware of connected concepts. Nevertheless, other classifications might be possible, for example, by categorizing cueing based on cognitive outcomes rather than on function. In the next section, the functional framework of cueing will be used as a frame of reference in our discussion of the studies that have applied cueing to learning from animations.

Cueing in animations

Several researchers have argued that learning from animations may be enhanced if learners' attention is guided to essential information in an animation (Bétrancourt, 2005; Mayer & Moreno, 2003; Lowe, 1999). For example, Bétrancourt (2005) proposes the 'attention guidance principle', stating that for information extraction to be effective, cueing should be used to guide the learners' attention to important components of an animation. However, the use of cueing in animations has for the most part been based on intuitive recommendations that cues will facilitate the learning process and are often not considered as the main variable in the analyses. Nevertheless, very recently, several studies have systematically examined the instructional value of adding one or several cues to an animation. Table 2 provides an overview of the studies on cueing in animations and summarizes their characteristics and main findings.

The studies presented here used cueing to serve at least one of the functions that we described earlier in our framework of cueing. To avoid a redundant presentation of the studies that have investigated multiple types of cues in a single study or have studied one type of cue to achieve multiple functions simultaneously, our discussion of the effects of cueing in animations is not structured according to the three functions of cueing specified in our functional framework. Instead, we first describe the studies in which cueing facilitated learning followed by the studies in which cues were not beneficial for learning. The framework is used to identify the type(s) of cueing and the function(s) that cueing was intended to fulfill in each study.

Instructional cues that improve learners' understanding

Some studies reported a positive influence of cues on learning and memory performance. In an influential study, Mautone and Mayer (2001) investigated whether cueing a system-paced multimedia lesson of the principles of how airplanes achieve lift fosters the construction of a coherent and integrated schema. Cueing was done by varying the tone and pitch of key words or phrases in the narration and/or different types of visual graphical cues, including colored arrows, icons, color coding, and color contrast. Verbal cueing and the colored arrows had the function of *guiding learners' attention to essential information,* whereas icons were used to *emphasize the organization of the instruction*. To support the integration process such as inferring causal mechanisms, color coding was used to *relate elements between representations* and color contrasts were used to *relate elements within representations*. Results revealed that verbal cueing had a strong beneficial effect on problem-solving transfer, whereas highlighting the components and their relations with visual cues in the animation proved to be ineffective. A plausible explanation for the latter finding that is in line with our framework of cueing might be that the animation itself contained simple elements and relations and had a well-defined structure. That is, the animation was not complex enough to require the extra guidance of the visual cues.

Further, Boucheix and Guignard (2005) studied different types of cueing simultaneously in learning the operation of gears in younger adults. Both visual (i.e., color) and verbal (i.e., text sentence) cues were used to facilitate learners' processing of the animation. Whereas the use of color had the function of *guiding attention to essential information*, the verbal cues served the function of *making (temporal) relations within a representation more explicit*. Positive effects of cueing were found on immediate comprehension and delayed retention, especially if learners themselves could control the presentation (see also Boucheix, 2008). However, it is not clear from this study which type of cueing or what function of cueing has led to these results as no attempt was made to analyze their effects separately. For example, it seems that the verbal cues not only directed attention but also increased learners' engagement in cognitively processing the animation.

In addition to studies that have found beneficial effects of verbal cues or verbal and visual cues together, there is evidence that visual cueing alone can also improve the understanding of animations. In a study evaluating students' ability to learn the functioning of enzyme synthesis from a narrated animation, Huk, Steinke, and Floto (2003) examined the added value of non-verbal cues. They used color, arrows, and visualized technical terms to serve two functions of cueing. The function of the arrows and the coloring of relevant objects was *guiding attention to essential information* in the animation. The function of visualizing technical terms was *relating elements between representations* (i.e., animation and accompanying narration). The results showed that cueing resulted in a better learning performance. Nevertheless, it may be argued that cueing not only related elements from the narration to the corresponding elements in the animation, but also added additional information by displaying multiple technical terms visually that could have served as labels that facilitated cognitive processing over and above emphasizing key information (cf. Mayer, 1989). Moreover, the extra information provides information on a deep semantic level and thus can not be considered a simple visual cue to guide attention.

More convincing evidence for the hypothesis that learning from complex animations can be enhanced by a simple visual cue comes from a study by De Koning et al. (2007). In their study, learners were required to study a non-narrated complex animation illustrating the dynamics of the main processes of the cardiovascular system. One group studied the animation with a visual color contrast cue highlighting one specific process (i.e., the valves system), whereas another group studied the animation without visual cues. The function of the visual color contrast was *guiding attention to essential information* in the animation. It was found that emphasizing particular content significantly improved comprehension and transfer performance on both the content that was cued as well as on the content that was uncued. No differences were found in the amount of cognitive load, but given the higher learning performances in the cued condition it was argued that visual cueing lead to a more effective use of WM resources. Together with the study of Mautone and Mayer (2001) this study seems to suggest that the effectiveness of visual cues is dependent on the complexity of the instructional animation and only improves learning if learners need cues to assist them in constructing a coherent representation. This would be in line with the Jeung et al. (1997) study that has demonstrated that the degree of visual complexity of instruction seems to be a crucial factor for the effectiveness of cueing.

The empirical findings discussed above suggest that deviating from the realistic depiction by manipulating the visuospatial characteristics (e.g., color, luminance) of a complex animation may foster processing and understanding (cf. Dwyer, 1978). In addition, Fischer, Lowe, and Schwan (2008) have argued that also temporal properties (e.g., velocity) of an animation may have visuospatial effects and therefore may be used as cues to (re)direct learners' attention to relevant parts. Changing an animation's speed may influence the relative perceptual salience of the elements in a dynamic display (i.e., dynamic contrast, Schnotz & Lowe, 2008), which may effectively influence what information is extracted from the animation for further processing. To investigate whether various presentation speeds

Table 2 *Summary of the studies on cueing in animations and their characteristics*

	Modality of cueing	Type of cueing	Function of cueing	Positive cueing-effect on learning	Type of knowledge test
Boucheix & Guignard (2005)	Visual and verbal	Color Arrows Text (written)	Guiding attention Highlighting relations (within representations)	Yes (combination verbal/visual cueing)	Immediate and delayed comprehension
De Koning, Tabbers, Rikers & Paas (2007)	Visual	Luminance contrast (spotlight-effect)	Guiding attention	Yes	Comprehension Transfer
De Koning, Tabbers, Rikers, & Paas (in press)	Visual	Luminance contrast (spotlight-effect)	Guiding attention	No, but cues guide attention	Comprehension Transfer Verbal protocol
Fischer & Schwan (2008)	Visual	Movement (speeding up) Arrows	Guiding attention	Yes, especially movement	Comprehension/transfer
Fischer, Lowe & Schwan (2008)	Visual	Movement (speeding up)	Guiding attention	Yes	Verbal protocol Comprehension/transfer
Huk, Steinke & Floto (2003)	Visual	Color Arrows Text (written)	Guiding attention Highlighting relations (between representations)	Yes	Comprehension
Kriz & Hegarty (2007)	Visual	Arrows	Guiding attention Highlighting relations (within representations)	No, but cues guide attention	Comprehension/ troubleshooting

Large, Beheshti, Breuleux & Renaud (1996)	Visual	Text	Guiding attention Highlighting relations (between representations)	No	Recall Comprehension Problem-solving
Lowe & Boucheix (2007)	Visual	Movement Color	Guiding attention Highlighting relations (within representations)	Yes	Comprehension
Mautone & Mayer (2001)	Visual and verbal	Arrows Intonation Color	Guiding attention Emphasizing organization Highlighting relations (between representations)	Only verbal cueing	Retention Transfer
Moreno (2007)	Visual	Color	Emphasizing relations (between representations)	No	Retention Transfer
Schneider & Boucheix (2008)	Visual	Arrows	Guiding attention Highlighting relations (within representations)	No	Comprehension
Van Oostendorp & Beijersbergen (2007)	Visual	Color	Guiding attention Highlighting relations (between representations)	No	Retention Comprehension Transfer

emphasize different elements, they set up a study in which learners studied an animation that showed the workings of a pendulum clock at normal presentation speed or at a highly increased presentation speed. The cue (i.e., playing speed) thus had the function of *guiding attention to essential information*. Results revealed that parts of the clock that are functionally relevant but perceptually less conspicuous in the normal speed version were mentioned significantly more often in the fast version. Moreover, participants in the fast version also included more correct concepts about these parts in their written descriptions. These results provide evidence that temporal manipulation of an animation's presentation speed may increase attention to specific elements and thereby facilitate understanding.

In a related study, Fischer and Schwan (2008; also see Fischer, 2008) investigated whether manipulating the speed of the animation (i.e., dynamic cueing) and arrow cues were equally effective at directing attention in an animation. Although the function of both types of cueing was *guiding attention to essential information*, they differed in how attention was directed (dynamic contrast vs. visuospatial contrast, Lowe & Boucheix, 2008). Results demonstrated that altering the playing rate of the animation was a significantly more effective cue for making certain aspects of the animation more salient and directing attention towards those elements than having learners study the animation with locally focused arrow cues. It thus seems that varying temporal properties of animations to serve as cues is more effective for directing attention and improving learning than adding visual cues such as arrows to the display.

A study by Lowe and Boucheix (2007) provides further support for the notion that dynamic cueing may improve learning. In their study, they examined a form of 'continuous cueing' by presenting learners an animation of a piano mechanism with a dynamic spreading color cue. The visual colored path continuously provided a close temporal and visuospatial resemblance to relevant information and occurred synchronous with the visualization of the main causal chains. Cueing improved understanding of the kinematics and functional model of the piano mechanism, suggesting that the spreading color cue effectively enhanced cognitive processing. Lowe and Boucheix (2007) argued that the continuous cue produced an altered viewing pattern, that is, it introduced a new way of looking, which may have stimulated learners to cognitively process the content more deeply. Eye-movement data, collected in the study phase, support this conclusion. The success of this type of cueing may lie in the fact that it served not only the function of *guiding attention to essential information* but also functioned to *relate elements within a representation* (i.e., it made temporal relations more explicit), which may have increased cognitive engagement and subsequent understanding of the animation.

In short, several studies have demonstrated that verbal and/or visual cues as well as cues that manipulate an animation's temporal properties may improve comprehension and transfer performance, indicating that cueing may be effectively used to improve learning from animations.

Instructional cues that fail to facilitate learning

Despite the generally positive findings of the cueing studies in animations we have discussed so far, an increasing amount of evidence demonstrates that visual cueing does not necessarily improve learning. Within this work, research has explicitly, but not exclusively, focused on the effects graphical cues have on the comprehension of a visual-only animation without text.

In a study comparing two groups of students that studied a user-controllable animation showing the steps in a flushing cistern mechanism with or without arrows to *guide attention to essential information* and arrows to *emphasize causal relations between components or inferences*, Kriz and Hegarty (2007) found no evidence of a benefit of cueing on comprehension. To investigate why visual cueing did not produce the expected learning benefits, Kriz and Hegarty (2007) set up an eye-tracking experiment to test whether the arrow-cues captured attention and caused learners to look at the cued information. Interestingly, results revealed that the arrow-cues directed more attention to relevant information, but this did again not result in a better understanding of the information presented in the animation than studying an animation without visual cues (see also Schneider & Boucheix, 2008).

In a related study, De Koning, Tabbers, Rikers, and Paas (in press) also tried to identify the underlying mechanism of attention cueing. In their study, eye-tracking and verbal reporting techniques were used to unravel the perceptual and cognitive processes involved in learning from an animation of the cardiovascular system in which none, one, or all of its subsystems were successively cued using a spotlight-cue (i.e., luminance contrast). The function of the spotlight-cues was *guiding attention to essential information*. Results paralleled those of Kriz and Hegarty (2007). Thus, both studies suggest that visual cues effectively capture attention, but do not necessarily improve understanding of the content. This pattern of findings may be particularly true for learners with low spatial abilities (Schneider & Boucheix, 2008). A critical requirement for cueing to be effective is that the cues are designed to facilitate rather than to interfere with the processing of an animation. In fact, an improper use of cueing might be ineffective and even increase cognitive load on the learner. This was demonstrated in a study by Moreno (2007), in which prospective teachers studied effective teaching skills with or without visual cues. In the cueing condition, the critical teaching skills that were visualized in the animation were highlighted in a bright red color on a step laddered list containing the labels for each skill. Cueing the labels accompanying the skills when they were illustrated in the animation had the function of *guiding attention to essential information* and *relating connected elements between representations*. Results showed that the cues did not improve learning performance. Moreno (2007) argued that cueing may have forced learners to spatially split their visual attention between the animation and the highlighted labels that were presented side-by-side, and therefore may have interfered with the learning process. Moreover, this study indicates that the effects of highlighting multiple elements simultaneously without a specific order may hinder learning. Visually highlighting to relate skills and labels to try to control cognitive load may have activated another cause of extraneous load (i.e., splitting one's attention between different representations), which is indicative of the magnitude of the cueing effect and the sensitivity of cueing to individual design features (Ayres & Paas, 2007b).

Similarly, Large, Beheshti, Breuleux, and Renaud (1996) studied the effects of cueing in an animation of the cardiovascular system by using text captions (e.g., "This animation shows the flow of blood through the RIGHT side of the heart"). The captions were fragments of the textual description that were added to the animation and thus did not provide new information. Specifically, the functions of the captions were *directing attention to essential information* in the animation and *relating elements between representations* by placing captions in the animation to establish a link between specific parts of the animation and the accompanying textual description. Adding captions to the animation did not improve learners' understanding of the system, especially for complex content. The authors believed that this lack of effect may be due to the labels that were included in the animation. As labels are known to improve memory performance themselves (Mayer, 1989), they may have made the captions redundant, which consequently added little to understanding the content. Hence, the characteristics of an animation and cueing influence each other and should be properly aligned to optimize the effectiveness of cueing in animations.

Furthermore, Van Oostendorp and Beijersbergen (2007) studied the effects of cueing by highlighting a part of the animation and simultaneously placing a dot before the sentence referring to that part of the animation. The functions of the cues were *guiding attention to essential information* in the animation and *relating elements between representations*. Results revealed that the cueing condition did not perform better than the no-cueing condition. A reason for this might be that in contrast to the color-coding relating specific words and small pictorial elements used by Kalyuga et al. (1999) cueing in the Van Oostendorp and Beijersbergen study did not relate specific concepts in the text with the corresponding elements in the visualization. This suggests that cueing might not have been specific enough to facilitate processing in this study.

In summary, an increasing number of studies demonstrate that cueing in animations does not facilitate cognitive processes that foster deep understanding such as making causal inferences and forming an integrated representation. If any cueing-effects are observed, they tend to be restricted to enhancing lower-level processes, such as identifying, selecting, and extracting information.

Discussion

This article examined the transferability of cueing methods that have proven to be successful for facilitating the processing of text and/or static visualizations to processing instructional animations. The main finding of our analysis of the effectiveness of cueing in animations is that the evidence is mixed. Table 1 summarizes the main perceptual and cognitive effects of cueing on learning from dynamic and static representations. It is important to note that studies on cueing in animations have investigated some functions of cueing more extensively (e.g., attention-directing function) than others (e.g., organizing function) and did not always provide straightforward interpretations of the effects of the functions of cueing. Regarding the function of focusing attention, the findings indicate that cues that highlight specific locations can be effectively used to guide the process of selecting relevant information in animations, but do not necessarily help learners to infer crucial causal relations. Furthermore, cues that emphasize the relations between elements within and/or between representations to enhance their integration have mainly shown no benefits for learning from animations. However, some studies did show better learning with relational cues, but were unable to solely ascribe the improved learning to the relational cues. Moreover, organizational cues that highlight an animation's structure have also not yet proven to be successful. Overall, the conclusions regarding the effectiveness of the different functions of cueing in animations are disappointing and less clear than in learning from text and static graphics.

There are several arguments as to why cueing approaches that have proven to be successful in learning from static representations do not seem to improve learning in animations: 1) cues as they have been used until now, do not have their potential fully exploited yet, 2) cues guiding learners' attention to specific screen locations are overridden by attention-catching elements in an animation, 3) learners do not perceive cues as relevant for learning.

1) Cues do not have their potential fully exploited

An interesting observation is that many studies examining cueing in animations did not identify the unique function of each cue and showed a large diversity in design considerations (e.g., narration or not, pacing or not). Specifically, using cues with multiple functions such as in the Kriz and Hegarty (2007) study might confuse learners and hinder learning. Moreover, not every cue engaged learners in meaningful learning activities like in the Moreno (2007) study, in which the effectiveness of relational cueing may have been reduced because cues required processing that did not seem to be relevant. Also, several studies have used cues that lack specificity (e.g., Van Oostendorp & Beijersbergen, 2007). However, even effectively designed cues that guide learners' attention to specific parts do not guarantee enhanced understanding. Rather, the studies of Kriz and Hegarty (2007) and De Koning et al. (in press) suggest that not only the time spent on task-relevant information but also what constructive activities (e.g., generating inferences) are employed within that period of time determine whether learners will reach a thorough understanding. Thus, cueing seems very helpful for guiding attention to specific parts of an animation but it is not *sufficient* for building a good conceptual understanding from an animation.

In sum, at this point in time the majority of studies did not use cues in a very well thought-out way, which does not allow us to draw any generalizable conclusions yet. Future studies that use the functional framework will have to reflect the full potential of cueing to improve learning from animations.

2) The dynamics of an animation override attention cueing to specific screen locations

An alternative explanation for the ineffectiveness of cueing in building an integrated mental model concerns the powerful effect that dynamic characteristics of animations may have on the distribution of attention. Elements of an animation that stand out against the rest of the display due to their movements (i.e., dynamic contrast) are likely to attract attention (cf. Hillstrom & Yantis, 1994). Consequently, the dynamic capture of attention may outcompete visual cues that direct attention to discrete parts of information and individual locations. In fact, Fischer and Schwan (2008) have provided preliminary support for the assumption that in animations a dynamic contrast due to movements is more effective for capturing attention than a visuospatial contrast. However, the overriding effect of dynamic contrast of animated elements may be overcome by using dynamic cues that make an animation's temporal information such as sequential relations more explicit, but this was only explored in one study (Lowe & Boucheix, 2007).

In short, the dynamic contrast created by moving elements of an animation may be more apt at capturing attention than the non-dynamic cueing methods that have been applied to animations and thus may reduce the effectiveness of cueing. Therefore, exploring more dynamic attention guiding mechanisms may be more fruitful (Fischer, 2008).

3) Learners do not perceive cues as relevant for learning

In animations learners can directly perceive temporal changes, whereas understanding the same content from static representations requires a process of internal animation (Hegarty et al., 2003). Therefore, learners may be much more cognitively engaged in learning from static representations of dynamic systems than from animations. Asking learners to study and to try to comprehend an animation may be a task that lacks specificity. Therefore, learners often do not know what is expected from them in terms of how thorough they have to study the animation in order to be able to answer the test items and may reduce their efforts to actively process the presented information thereby reducing the possibility of benefiting from cues. Moreover, the fact that cues indicating relevant information and relations are not used as hints to engage in deep learning activities suggests that it may be needed to clarify what cues are presented in animations, how they are intended to facilitate learning, and to instruct learners how to use cues effectively.

In short, although cues may have the purpose of facilitating the organization or integration of information in animations, learners may not use the cues as such due to the learning task being ill-defined.

In conclusion, several factors such as the uncritical application of cueing methods from static instruction to animations, the dynamic character of animations, and the lack of learners' engagement with cues have been discussed as possible reasons for failures to find enhanced learning from cued animations compared with uncued animations. Therefore, it might be suggested that so far effects of cueing in animations are not studied adequately and might only provide an underestimation of the instructional potential of cues to improve learning from animations.

Implications and future research

At present, it is yet rather unclear under which circumstances cueing in animations will be effective. Therefore, systematically studying the instructional value of the different functions and types of cueing in animations is essential for a better understanding of cueing. In the following, the framework of cueing is used to set out several possible avenues for future research. In addition, guidelines for the instructional design of cueing in animations are derived from the framework that can be tested in further research.

Guiding attention to essential information

The majority of studies discussed in our analysis have tried to focus learners' attention on specific parts of animations using specific types of visuospatial contrasts. However, for a principled understanding of the effect of cues on guiding attention to essential information more systematic research is needed. For example, it might be studied whether certain types of cues may be more effective than others like enlarging relevant features (i.e., zooming in) or arrow cues. Moreover, it might also be valuable to investigate and refine forms of cueing using a dynamic contrast such as (dis)continuous temporal manipulation (Fischer et al., 2008). Furthermore, it might be interesting to study the manipulation of both visuospatial and temporal aspects like slowing down an animation when highlighted relevant information is encountered.

Another interesting approach would be to investigate attention cueing and simultaneously try to improve learners' cognitive engagement by encouraging them to actively process the animation using techniques that promote constructive processes such as self-explaining (Roy & Chi, 2005). Related to this, it may be worth examining whether giving learners a clear goal or purpose when studying a cued animation may encourage them to perceive the cue as relevant for accomplishing their task and consequently to process the presented information in a more elaborated way.

Furthermore, the level of expertise may have a strong influence on the effectiveness of cueing. According to cognitive load theory, directing novices' attention to essential parts of animations compensates for a lack of cognitive schemata and frees up cognitive resources for relevant learning activities. However, once learners are capable of discerning relevant from irrelevant parts of animations, visual cues may provide redundant information that cannot be ignored, and hence may cause unnecessary cognitive load that hinders learning (within cognitive load theory referred to as the expertise reversal effect, Kalyuga, Ayres, Chandler, & Sweller, 2003).

Emphasizing the organization of instruction

Animations usually contain multiple levels of dynamic information because events at the macro level can be decomposed into smaller events at the micro-level (Schnotz & Lowe, 2008). However, not all levels of dynamic change are of equal importance for the learning task and/or identifying the elements that constitute a group is difficult. For example, someone who is interested in the precise locomotive pattern of reef fish will concentrate on changes at the micro-level whereas someone who is interested in the global changes in the movement pattern of reef fish will focus on changes at the macro-level. Organizational cues may then be used to help learners in structuring the elements that belong together or distinguishing those that are of relevance for the learners' purpose. For example, the elements that form a unity can be grouped by giving them the same color as an indication that they belong together. Further, an animation's playing speed may be used as a cue to emphasize the level of change at which the organizational hierarchy is studied (Meyer et al., in press). That is, at higher playing speeds, the macro-information tends to be more salient, whereas at lower playing speeds, the micro-events become more noticeable. Therefore, playing an animation multiple times at different playing speeds may reveal different levels of the overall dynamic structure. This way the general structure of an animation is emphasized and can be used for further processing such as building a dynamic mental model at a more fine-grained level, that is, the elements that are part of this structure. However, more research is needed to substantiate this claim.

Integrating elements within and between representations

Several studies in our analysis suggest that visual cues relating corresponding elements between and/or within representations may be ineffective if relational cues lack the appropriate level of specificity and force learners to split their attention across different elements in space to be able to benefit from the cues. Therefore, we propose to study relational cueing more extensively based on a proper task analysis that takes these aspects into account in order to determine whether cues relating elements within representations, between representations, or the combination of both will result in better learning from animations.

In addition, animations differ substantially from static representations in their depiction of causal relations between elements that are distributed over time and the requirements to extract these relations (i.e., 'read off' vs. infer). Despite the many unsuccessful attempts to facilitate the extraction of temporal and causal relations with cues such as arrows described in our analysis, the Lowe and Boucheix (2007) study offers a concrete example of how an animation's implicit temporal relations may be made more explicit and can be readily extracted by using a moving cue. More research is needed, however, to develop and test similar and other (dynamic) cueing approaches that explicate the causal relations to be learned in various content-areas and with different types of animations. For example, it could be investigated whether an animation of the cardiovascular system can be made more effective if the blood flow is highlighted with a continuous spotlight-cue showing its trajectory. It is important to note that dynamic cues to foster the integration process may or may not overlap with dynamic cueing approaches to redirect attention, depending on whether the dynamic cues do or do not explicate spatio-temporal causal information.

Theoretical implications

Despite the recent studies that have investigated the utility of cues to improve learning from animation, it is yet unclear which aspects of cueing are responsible for its success or failure. Thus far, various theoretical frameworks have been used to explain the effects cues may have on learning from animation, but cognitive accounts predominate. However, the effects on attention of presenting change-related information in an animation and using visual cueing to facilitate perceptual processing suggests that if we wish to explain how and under what conditions cueing can help learning from animations, we need to broaden our approach and extend current cognitive accounts of cueing to encompass perceptual dimensions. For example, both Mayer's cognitive theory of multimedia learning and cognitive load theory provide insufficient understanding of the attentional and perceptual processes of cueing, as assumptions and explanations of these dimensions are not specified.

The few studies that have tried to gain more insight into the crucial factor(s) or underlying mechanism of attention cueing were unable to satisfactorily explain how cues influence processing of an animation. For example, the findings of Kriz and Hegarty (2007) and De Koning et al. (in press) that cues guide attention to crucial locations in the display, provides no solid basis for explaining the cognitive effects of cueing on learning performance. Further, a cognitive load explanation that assumes that studying an animation with attention-directing cues imposes less visual search and extraneous load has yet to be confirmed directly (De Koning et al., in press). In short, the lack of a comprehensive theory that encompasses all perceptual and cognitive aspects in learning from cued and uncued animations does not allow researchers to fully explain the effects of visual cueing. Future research should be aimed at integrating the predominantly cognitive accounts with current theories of visual cognition as a more appropriate framework for investigating how cueing might work in processing animations.

Practical implications

The extent to which research on the effects of cueing in animations produces general principles or practical guidelines is limited due to the fact that relatively little studies have examined cueing in animations and the findings have been mixed. However, some preliminary guidelines emerge from our analysis:

(1) Guiding learners' attention to specific locations in the display with attention-directing cues does not guarantee that learners infer essential causal relations. Therefore, other methods that induce cognitive activity need to accompany attention-directing cues to improve learning from animations.

(2) Although several studies have failed to find support for the use of visual cues such as arrows in animations, the recent findings by Lowe and Boucheix (2007) suggest that colorization of relevant features of an animation that occurs in temporal correspondence to events in the animation might improve learner understanding of the material. Thus, visual cues should guide attention both spatially and temporally.

(3) Cues designed to facilitate a specific type of processing (e.g., selection, organization, integration) may lose their potency if they are used in such a way that they impose unnecessary processing activities. For example, adding arrow cues to

static visualizations to indicate an element's direction of motion may be beneficial, but in animations, it may interfere with the learning process. Therefore, one should first specify the function(s) of cueing and then design the cue(s) accordingly.

Research based on these guidelines can be expected to significantly improve our understanding of the instructional potential of cueing in animations, and subsequently, to promote the development of more refined theoretical approaches. In addition, the three functions of cueing proposed in our functional framework may provide a useful distinction for studying the individual and combined effects of cues on perceptual and cognitive processing. In conclusion, in trying to make animations more effective with cues it is insufficient to simply apply successful cueing approaches from static representations, but requires the development of cueing approaches that work in animations.

Chapter

8

Summary and general discussion

The aim of this dissertation was to investigate whether learning from an instructional animation with many simultaneous changes and without text can be enhanced if the learners' attention is directed to relevant information in the animation by visual cues. Based on Cognitive Load Theory (Sweller, 1999) as well as the existing evidence of cueing in static (e.g., text, pictures) and dynamic representations (e.g., animations), it was hypothesized that cueing (i.e., luminance contrast) would reduce the ineffective or extraneous cognitive load associated with searching for relevant information in the animation, and thereby would facilitate learning as the freed-up working memory resources could be used for learning-related activities. In this dissertation, six studies were presented in which the effectiveness of visual cues on learning from an animation of the cardiovascular system was investigated. In Chapters 2, 3, and 4 it was investigated whether cueing specific parts of the animation of the cardiovascular system is an effective way to foster learning from the animation. Chapter 3 investigated whether or not the number of elements in the animation that should be processed per unit of time influences the effectiveness of cueing and Chapter 4 examined *how* cues influence the perceptual and cognitive processing of the animation. The studies presented in Chapters 5 and 6 tried to shed light on the role of explanations in learning from cued and uncued animations. In all studies the involvement of cognitive load was investigated by looking at invested mental effort. In Chapter 7, the effectiveness of cueing in animations and static representations was compared and a framework was presented for the different functions of cueing. In the current Chapter, the main results of the studies reported in the present dissertation are reviewed, the theoretical and practical implications of the findings are discussed, and some directions for future research are suggested.

Overview of the main results

Despite positive effects of cueing on learning from static pictures and/or text (e.g., Kalyuga, Chandler, & Sweller, 1999; Lorch, 1989), the first attempts to investigate cueing in animations have not shown improved learning from a simple cued animation (i.e., containing few elements that should be processed at the same time, Mautone & Mayer, 2001). The study in **Chapter 2** therefore investigated whether a cue that directed learners' attention to a key aspect of a complex animation (i.e., consisting of many simultaneously occurring changes), reduced extraneous cognitive load and hence could improve learning. Participants, who were divided into two groups, were required to learn about the main subsystems of the cardiovascular system. One group studied the animation with a visual cue on a single subsystem of the cardiovascular system (i.e., the functioning of the heart valves), whereas the other group studied the animation without the help of such a cue. Learning outcomes were measured by examining how both the cued and the uncued groups answered retention and transfer questions about cued information as well as the uncued subsystems of the cardiovascular system. This allowed us to determine the scope of cueing, that is, whether or not cueing only influences learners' understanding of the cued content and whether or not cueing certain aspects in the animation hinders the understanding of uncued aspects. After the animation and after each test, participants indicated the amount of mental effort they invested on a 9-point rating scale (Paas, 1992). It was found that learners who received the cued animation obtained better retention and transfer scores on both the questions about the cued and the uncued content than learners who received the uncued animation. However, no direct effects of cueing on mental effort were found. It may be argued that cueing frees up working memory resources that can be spend on activities that help learners better understand the cued and uncued information. Cueing may thus improve learning from the animation due to a more effective use of working memory resources.

The study in **Chapter 3** further elaborated on the cueing effect found in Chapter 2 and tested, using the same materials, whether the effect of cueing on learning is influenced by the number of elements that should be processed per unit of time in the animation. The number of simultaneous changes, and hence the cognitive load imposed on learners, was manipulated by presenting the animation at a high or at a low speed. The presentation speed of the cued and uncued animations was much faster or much slower than the presentation speed of the animation in Chapter 2. Cognitive load theory proposes that with an increasing number of relations that should be processed at once, the requirement to quickly search for essential aspects in an animation to process in more detail and, hence its associated ineffective cognitive load, also increases. This suggestion has been supported in several studies investigating cueing in static representations (e.g., Jeung, Chandler, & Sweller, 1997). Therefore, it was hypothesized that cueing should reduce ineffective cognitive load due to unnecessary searches and increase learning performance if the animation was presented at a high presentation speed, whereas cueing should be less necessary for reducing ineffective cognitive load and improving learning if the animation was presented at a low presentation speed. Contrary to expectations, learners who studied a cued animation at a high or at a low presentation speed were able to answer retention and transfer questions about cued and uncued information about the cardiovascular system as good as learners who studied an uncued animation at a high or at a low presentation speed. However, learners who studied the animation at a low presentation speed spent more time and invested more mental effort to obtain this performance than those who studied the animation at a high presentation speed. This study thus did not show the cueing effect found in Chapter 2, and hence did not support the notion that cueing should be especially effective at improving learning from the animation when required to process many elements at the same time. These findings suggest that it is necessary to examine in more detail what actually happens during learning from the animation in order to use cueing more effectively.

The findings in Chapter 3 formed the basis for a more in-depth analysis of the perceptual and cognitive processes involved in learning from cued and uncued animations. Therefore, the study in **Chapter 4** used the same methodology as the study in Chapter 2 but extended the design with process-related measures in order to shed light on *how* people learn from the animation of the cardiovascular system. Eye tracking was used to investigate attention allocation to the elements within the animation. This allowed us, for example, to determine whether cueing attracts learners' attention or not. Furthermore, insight into which cognitive processes occurred during learning was obtained by asking learners to retrospectively report the thoughts they had while studying the animation using a record of their own eye movements as a retrieval cue (i.e., cued retrospective reporting, Van Gog, Paas, van Merriënboer, & Witte, 2005). An additional focus of this study was to investigate whether cueing would be more effective for learning if multiple subsystems of the cardiovascular system would be cued in the animation instead of cueing a single subsystem. It was hypothesized that learners would look longer and more often at cued than at uncued parts of the animation. Furthermore, it was expected that visual search (i.e., extraneous load) would be reduced. In addition, it was expected that freed up working memory resources by cues would enable learners to improve their understanding of the content, especially the cued information, which would be reflected in the verbal protocol data as well as the retention and transfer tests.

As predicted, learners looked more often and for longer periods of time at cued than at uncued parts of the animation. Interestingly, when only one subsystem of the heart was cued, cues gained attention initially but the effect disappeared over time. However, no effects of cueing were found on mental effort and visual search. Furthermore, cueing had only a small influence on the learners' cognitive processing as indicated by the cued retrospective reports. Learners who studied the animation with a single cue generated more correct statements about the cued part than learners who studied the animation without cues. Contrary to the predictions, studying an animation with multiple cues did not lead to deeper cognitive processing than studying an animation with a single cue or no cues. Moreover, similar to the results of Chapter 3, cueing did not lead to higher scores on retention and transfer questions about the cued and the uncued parts of the cardiovascular system. These findings suggest that cues can effectively direct learners' attention to specific locations in an animation but cues do not ensure that the conceptual relations between the different components of the cardiovascular system are identified (also see Kriz & Hegarty, 2007). Therefore, it is concluded that attention-directing cues help learners in extracting relevant information from animations, but such cues seem not sufficient to get spontaneously engaged in active knowledge construction activities. Therefore, to increase the possibilities for cueing to have an effect on conceptual understanding it may be more important to support learners in focusing their invested mental effort on learning-related activities (i.e., germane load, Paas, Renkl, & Sweller, 2003) rather than just trying to improve the design of the animation.

Having established that cueing mostly influenced learners' perceptual processing and not so much their cognitive processing (see Chapter 4), **Chapter 5** and **6** focused on stimulating the learners' internal knowledge construction processes in order to actively process the presented information and to increase the possibility of obtaining a cueing effect on conceptual understanding.

In the study described in **Chapter 5**, learners were required to study an animation of the cardiovascular system under one of four experimental conditions. One group studied the animation in which all subsystems of the cardiovascular systems were sequentially cued while learners were prompted to explain aloud to themselves why the movements and changes of the elements in the animation occurred. A second group studied the animation without cues but learners were still prompted to generate self-explanations during the animation. The third and fourth groups either studied a cued or an uncued animation of the cardiovascular system but were not prompted to generate self-explanations while viewing the animation. It was argued that only if the animation had cues that reduced working memory load associated with searching for specific elements, learners would have sufficient working memory resources available for establishing the causal relations that are fundamental to building an integrated mental representation from the animation. Therefore, it was hypothesized that learning from a cued animation would be improved by generating self-explanations whereas self-explaining with an uncued animation would not improve learning. Alternatively, it may be argued that by consecutively cueing different subsystems of the cardiovascular system, a structured sequence of meaningful functional elements is provided to learners which they can use to organize their self-explanation activities. Furthermore, it was also predicted that self-explaining with a cued animation should elicit more meaningful types of self-explanations than self-explaining with an uncued animation. As predicted, the results indicated that, compared to the other three groups, the learners who self-explained with a cued animation had higher scores on retention, inference, and transfer tests. No differences were observed between the three remaining groups. Furthermore, all four groups reported an equal amount of invested mental effort. Based on cognitive load theory it could still be argued that compared to all other groups, the cued self-explanation group used their working memory resources most efficiently, which was supported by an analysis on the efficiency scores. Furthermore, the content of the self-explanations showed that, in line with the predictions, cueing elicited more meaningful types of self-explanations that hence were positively correlated with test score performances on all learning outcome measures. These findings suggest that self-explaining can be effectively extended from the understanding of texts and/or static pictures (Ainsworth & Loizou, 2003; Butcher, 2006) to learning from cued animations in order to stimulate learning of a dynamic system's underlying principles and relations. On the other hand, self-explaining with an uncued animation in which learners might not focus their cognitive processing on specific parts of the animation may hinder the construction of a coherent mental representation (Renkl & Atkinson, 2007).

Whereas the study in Chapter 5 tried to improve the effectiveness of cueing by prompting learners to generate explanations to themselves about the functioning of the cardiovascular system, the study reported in **Chapter 6** investigated whether learning from a cued animation could be further improved if the explanations are not generated by the learner but are provided to the learner in a narration accompanying the animation. As in Chapter 5, one group generated self-explanations while studying a cued animation and a second group generated self-explanations with an uncued animation. In addition, there was a third and a fourth group who studied either a cued or an uncued animation both with a narration describing the crucial relations depicted in the animation of the cardiovascular system. It was hypothesized that generating self-explanations and receiving instructional explanations would improve learning outcomes if learners studied a cued animation but not if they studied an uncued animation, because both cognitive activities require a considerable amount of working memory resources to extract and process the animation's most crucial relations. Furthermore, self-explaining is prone to error and may lead to incorrect inferences whereas instructional explanations provided via narrations communicate correct information.

Therefore, it was also hypothesized that learners studying an animation with narrations outperform those who are required to generate self-explanations during the animation. Results demonstrated, as predicted, that generating self-explanations and receiving instructional explanations improved retention, inference generation, and transfer performance, when studying a cued as opposed to an uncued animation. Furthermore, irrespective of cueing, instructional explanations only improved the number of correct inferences on the inference test compared to the self-explanation condition. In addition, no effects on invested mental effort were observed. These findings suggest that just stimulating learners to actively process the animation of the cardiovascular system through self-explaining or just providing the main principles and underlying relations of the cardiovascular system to the learner as a narration do not necessarily lead to differences in learning outcomes. Rather, it seems that it is essential that cues are provided in the animation so that learners can focus their constructive activities on the essential aspects of the animation.

Finally, **in Chapter 7**, a broader context of cueing was presented to shed light on the similarities and differences between the perceptual and cognitive consequences of cueing on learning from static and dynamic representations. A framework was developed for classifying three distinct functions of cueing, which is supported by a considerable number of studies on the effects of cueing on understanding text and/or static illustrations: 1) cues guide attention to specific screen locations (i.e., selection), 2) cues emphasize the structure of instructional materials (i.e., organizing), and 3) cues make relations within and between elements more explicit (i.e., integration). This framework was used to evaluate and discuss the available research on cueing in animations (including the studies described in Chapter 2, 3, and 4) in a broader context. The review revealed that cues that focus attention on specific aspects of animations effectively guide attention to the cued parts just as such cues do in static representations, but these cues are much less effective at facilitating the extraction of the required causal relations than in static materials. Furthermore, in contrast to static representations, a cue that emphasizes relations within and/or between elements and cues that highlight a topic's organizing structure do not seem to improve conceptual understanding in animations (but see Chapter 6). Several reasons as to why successful cueing approaches in learning from static representations do not seem to improve learning in animations are proposed, including the suboptimal way that cues have been investigated in animations, the dynamic characteristics of animations, and the lack of learners' engagement with cues. Furthermore, practical and theoretical implications were discussed and it was concluded that cueing approaches should be developed that work in animations rather than uncritically applying cueing approaches that have proven successful in learning from static representations.

Discussion and conclusion

The studies described in this dissertation were set up to investigate whether attention cueing is an effective means for enhancing learning from an animation with multiple simultaneously occurring changes. Based on cognitive load theory, it was hypothesized that cueing would reduce visual search and its associated extraneous cognitive load and would improve learning from the animation. This section will take a closer look at the main findings of this dissertation and will discuss the results in light of the main theoretical framework and the hypotheses that followed from it.

The results of the studies in this dissertation indicate that for improving the understanding of change-related information from an instructional animation, simply adding a single visual cue or multiple visual cues to an animation is not sufficient. In four studies (Chapters 2, 3, 4, and 5), a direct comparison was made between learning from cued compared to uncued animations without textual explanations, but only in one of these studies (Chapter 2) studying a cued animation resulted in better learning performances than studying an uncued animation. This does not provide evidence that guiding attention with cues in an instructional animation leads to better learning than studying the animation without cues. It is yet unclear under which circumstances cueing in an animation without text may enhance learning. In our studies, the effect of cueing on learners' understanding of the animation was relatively small. However, we have studied just one type of cueing (i.e., luminance contrast) in one type of animation (i.e., cyclic animation). Further research with different types of animations and with different types of cueing is required in order to determine the effects of cueing on learning from animations.

Furthermore, in none of the studies in this dissertation evidence was found for reduced cognitive load due to cues. Moreover, as has been directly demonstrated in Chapter 4, visual search was also not reduced. In addition, the study in Chapter 4 showed that visual cues only effectively influence perceptual processing by focusing learners' attention on specific parts of an animation, but do not guarantee further cognitive processing of the depicted content. Therefore, cues seem necessary for attending the right information but they are insufficient for a better understanding of the information.

Thus, the majority of studies in Chapter 2 through 5 do not support the hypothesis that cueing alone improves learning from an animation. This suggests that rather than directly influencing learning from animations, cueing is more likely to fulfill an enabling function in the learning process. That is, cues may provide structured guidance to relevant parts of an animation that may serve as input for a more elaborated way of processing the presented information.

Based on these findings, a second hypothesis was investigated, namely that if the cognitive processing on the side of the learner would be promoted in an animation, the effectiveness of cueing for developing a more thorough understanding of an animation and the chances of knowledge transfer would increase. The studies in Chapters 5 and 6 provide evidence that both prompting learners to self-explain the functioning of the cardiovascular system and processing narrations accompanying the animation that describe the functional relations of the cardiovascular system enhances learning, at least when the animation is cued. Only by providing cues that guided the learners' attention and allowed learners to generate meaningful self-explanations or provided a direct link between the narration and the animation the learners' understanding was improved. Learners' understanding of the uncued animation was not improved by just generating self-explanations or actively processing narrations accompanying the animation.

The fact that better learning performance was obtained in the cued than in the uncued condition without differences in overall cognitive load suggests that learners in the cued condition used their working memory resources more effectively than those in the uncued condition. Thus, similarly to the observation that cueing alone does not foster learning, simply encouraging constructive cognitive processing activities in learners does not necessarily lead to improved learning in animations but only seems to improve learning if the constructive activities are supported with cues.

Therefore, an important conclusion from the studies in this dissertation is that perceptual and cognitive processing might be considered to reflect separate aspects of the learning process, at least for the animation used in our studies, but both aspects should be fostered to achieve an accurate conceptual representation of the depicted information. Cueing only effectively improves learning from an animation if learners also engage in constructive activities. On the other hand, engaging in meaningful learning activities only leads to deeper understanding if cues enable learners to perform these activities in such a way that their cognitive activities are focused on the essential parts of the animation (Renkl & Atkinson, 2007). So, the combination of cues to facilitate learners perceptual processing and the active cognitive processing strategies to encourage cognitive processing in learners seems a highly effective instructional combination for improving learning from animations. If either cueing is left from the design of animations or learners do not engage in processing activities to understand the animation's functional relations, learning from animations is not likely to be improved.

Theoretical implications

The findings of this dissertation have some implications for the theoretical account of the cueing effect in animations as given by predominant theories of multimedia learning and instructional design such as the theories of Sweller (1999) and Mayer (2001).

In theories like Sweller's cognitive load theory and Mayer's theory of multimedia learning, a cueing effect is assumed to occur because working memory is used more effectively if attention is guided to relevant aspects of the instructional materials, thereby reducing the ineffective cognitive load associated with searching for information in order to have more cognitive resources available for further processing of relevant information. Based on this reasoning, cognitive load theory might explain much of the reported results by arguing that the contribution of the different load types has changed due to cues without influencing total cognitive load. That is, the cues could have resulted in a substitution of extraneous to germane cognitive load because the investment of mental effort is focused on essential activities (i.e., germane load) without having to engage in irrelevant activities (i.e., extraneous load). Three of the studies in this dissertation (Chapters 2, 5, and 6) support such a cognitive load explanation of cueing on learning by showing that given equal amounts of cognitive load for the cued and uncued conditions, studying a cued animation resulted in better learning outcomes than studying an uncued animation. In these studies, learners thus seem to have used their working memory resources more effectively due to cues.

However, not all of our findings, especially those in which learning outcomes were not improved by cueing, can be explained by such a substitution explanation. In three studies (Chapters 3, 4, and 5), learners reported equal amounts of mental effort despite the fact that no differences were found in learning performances between cued and uncued animations without explanations. The fact that a reduction in cognitive load was not observed could indicate that the type of cueing used in our studies did not really influence cognitive load and therefore no differences were reported. However, as discussed above, in some studies evidence was found that the cues did lead to a more effective investment of mental effort, so it is unclear why cognitive load was not reduced in the studies reported in Chapters 3, 4, and 5. Moreover, the study in Chapter 3 even reported cognitive load results that seemed to go against the predictions made by cognitive load theory or could not be accommodated by it.

It should be kept in mind that explanations and assumptions concerning each type of cognitive load can not be tested directly, because at present there are no measures to distinguish directly between the three different cognitive load constructs intrinsic, extraneous and germane load. As some of the studies in this dissertation manipulated more than one type of cognitive load at the same time and cueing might have influenced different load types (i.e., decrease of extraneous and increase of germane load) together, definite conclusions regarding the role of cognitive load and the feasibility of cognitive load-related explanations cannot be drawn. Nevertheless, the findings in this dissertation suggest that it is important to use experimental designs and/or to develop cognitive load measures that allow for the identification of individual contributions of each load type and to test alternative explanations in order to gain more insight into the precise role that cognitive load plays in learning and to be able to test cognitive load theory-based hypotheses more effectively.

It can be argued that an explanation of cueing that mainly focuses on cognitive factors is unsatisfactorily in explaining the effects of cueing on processing animations but should also consider perceptual dimensions. In Chapter 4, for example, it was demonstrated that cueing is mainly concerned with early perceptual processes and has no or only little influence on cognitive processing in learners. This finding is supported by research investigating the effectiveness of arrow-cues on the understanding of a mechanical system (i.e., flushing cistern, Kriz & Hegarty, 2007) and therefore seems to hold for different types of cueing and for different animations. Moreover, such specific effects of cues are not restricted to learning from animations but have also sometimes been reported in research on cueing to facilitate processing of text (Lorch, 1989). Despite the fact that both cognitive load theory and Mayer's theory of multimedia learning mainly focus on working memory limitations, some explanations and findings derived from these theories such as the split-attention effect (Sweller et al., 1998) are based on perceptual and attentional phenomena. In line with this, the results of this dissertation suggest that perceptual aspects should be treated as a (more) critical aspect of cognitive load theory and Mayer's theory of multimedia learning in order to make specific predictions and to fully explain the effects of cueing on learning.

The results of the studies in this dissertation also suggest that another aspect, namely a detailed account of the processes that actually occur during learning, is required in theories that wish to explain perceptual and cognitive processing in animations. Although current theories on learning and instruction such as cognitive load theory and Mayer's theory of multimedia learning have mainly focused on learning outcomes, several recent studies using these theories as the main theoretical framework have tried to uncover the underlying processes of learning from dynamic systems via animations and static pictures (Scheiter & Van Gog, in press). Nevertheless, insights from other fields such as the domain of text comprehension, in which there is a fairly good understanding of how learners achieve a more thorough understanding of dynamic systems, could gain more knowledge about what learning from animations may entail in order to design effective animations and further improve cognitive load theory and Mayer's theory of multimedia learning. In Chapters 5 and 6 a broader approach was taken by introducing instructional techniques from text comprehension research such as self-explaining that are known to improve the learners' comprehension. The information from the text comprehension literature seemed to be more useful than cognitive load theory for the formulation of specific and detailed hypothesis and for providing an adequate theoretical account of the observed findings, such as why generating and receiving explanations with an animation have led to the same transfer performances (Chapter 6). It might thus be argued that a multidisciplinary perspective is needed to improve and refine current theories on cognition and learning such as cognitive load theory by building on theories and previous research from various disciplines and/or research traditions (cf. Ayres & Paas, 2009). It has, for example, already been demonstrated that important insights from embodied or grounded theories of cognition (for an overview, see Barsalou, 2008) can effectively be used to extend cognitive load theory in order to design effective animations (Ayres, Marcus, Chan, & Qian, 2009). According to embodied theories, mental representations of even abstract knowledge are grounded in sensory experiences, so processing these representations involves some form of sensory simulation. Even for learning the dynamics of abstract dynamic systems, embodied theories would predict that the movements of the depicted system might be understood by enacting that movement.

Our findings also have some more specific implications for theories and findings originating from the field of text comprehension. In Chapters 5 and 6 it was demonstrated that self-explaining is not only an effective strategy for improving learners' understanding of dynamic systems from texts (Chi, de Leeuw, Chiu, & LaVancher, 1994), diagrams (Ainsworth & Loizou, 2003), and text and pictures (Butcher, 2006), but also from animations without text. This finding suggests that other strategies from text comprehension research that are aimed at improving learners' comprehension of dynamic systems, such as reflection on learned information, might also be effectively used to enhance learning from (cued) animations about dynamic systems.

Practical implications

Besides theoretical implications, some practical implications follow from the results of the studies presented in this dissertation. As has become clear, looking at an instructional animation without spoken and written text that involves many simultaneous changes does not necessarily result in learning the functioning of the depicted system. Nevertheless, these animations can be an effective means for teaching about concepts of change, provided that both perceptual and cognitive processing of the learner is supported. As the studies in this dissertation show, one way to realize this support is by augmenting animations with cues that help learners to focus on the relevant parts of the content, particularly if this is combined with activities that encourage learners to actively process the information in the animation more deeply such as the generation of explanations about the functioning of the depicted system or studying functional explanations from other learners or experts.

The findings presented in this dissertation also suggest that, although promoting cognitive processing should occur in combination with cues in the animation, there are multiple ways to help learners effectively process the crucial information from animations more deeply in order to develop an accurate understanding of the animation. Providing learners with the crucial knowledge about the system depicted in the animation via narrations appeared to be as effective as requiring learners to come up with the information themselves. In light of the chances of implementation in education the former strategy seems most suitable as it might be more structured and easier to implement in a real classroom. For example, a biology teacher may explain the functioning of the cardiovascular system while at the same time an animation of this system is presented on a digital screen next to the teacher in which the elements the teacher is explaining are highlighted by cueing them.

Furthermore, the functional framework of cueing presented in Chapter 7 may also have important implications for when and how to use cueing in instructional animations. The framework provides a useful classification for the different functions of cueing and gives detailed information about the precise role of different types of cues. This may help teachers and instructional designers in deciding whether or not to use cueing in animations and to gear the type of cueing to the purposes of instruction in order to help learners in achieving a specific learning goal. For example, the framework suggests that cues may only direct attention and should therefore be combined with the engagement in constructive activities if the learning goal is to improve the understanding of an animation. The framework and the findings that it has produced or will follow from it in further research provide teachers and instructional designers with an increasing knowledge base that allows them to make more informed decisions about which cues should be used in what situations and under what circumstances in order to use animations effectively as instructional materials.

Directions for further research

The studies presented in this dissertation reflect a relatively recent line of research in learning from animations and educational psychology. Although several years ago studies reporting the effect of cueing in animations were rare, recently some studies investigating cueing in animations have surfaced in the literature (e.g., Boucheix & Lowe, in press; Kriz & Hegarty, 2007). Nevertheless, many aspects remain to be addressed in this area. The majority of studies that have examined the effects of cueing on the processing of animations have only studied cues that are aimed at guiding learners' attention to specific locations in animations (including Chapters 2, 3, 4, 5). However, as already indicated in the functional framework presented in Chapter 7, cueing may also serve the functions of emphasizing the organization of the content and making learners aware of related elements within and/or between representations. To further investigate the instructional effectiveness of cueing in animations and to cover the full spectrum of functions, research is needed that focuses on whether and how organizational and relational cues influence learning from animations with and without text.

Moreover, some aspects of the studies reported in this dissertation need to be further investigated or corroborated through further research in order to make more definitive claims about the attention-guiding function of cueing. An important aspect in this respect concerns the generalizability of the reported findings. For example, the presented studies were carried out with only one cyclical animation that showed a cause-and-effect system and was presented system-paced without textual explanations (except for Chapters 5 and 6). Moreover, only one type of cueing, namely spotlight-cueing, was used, which may or may not generalize to other types of cueing such as arrows. On the one hand, some of these aspects such as the primarily perceptual effect of spotlight-cueing, may be generalized more broadly, as consistent findings have been obtained that were in line with previous research (Kriz & Hegarty, 2007). In addition, findings could also be replicated from a laboratory setting to a classroom setting and from university students to secondary school students. These indications provide some credibility to the robustness of the observed findings. On the other hand, further research addressing the limitations of our studies by, for example, using different types of animations, different types of cues, and other types of learners could further strengthen our conclusions.

Furthermore, the presented studies have tested comprehension and transfer of acquired knowledge, but the tests were taken only directly after the experiments. From an educational perspective, it would be interesting to examine whether and to what extent the learned information is consolidated and remains useful after a more extended period of time. This may be especially relevant if one wants to dig more deeply into the actual processes of learning from cued and uncued animations, such as how learning by generating (i.e., self-explaining) or receiving instructional explanations (i.e., narration) differs (see Chapter 6). Research on the testing effect, for example, has already indicated that actively retrieving or generating information results in better long-term memory performances compared to reading or hearing the information (Roediger & Karpicke, 2006). Future research should therefore take into account long-term testing of acquired knowledge as well.

Another aspect that requires further investigation is the precise role of cognitive load in studying cued and uncued animations. Although the use of self-report scales gives a reliable indication of relative differences in cognitive load, it does not provide direct information about the types of cognitive load that are imposed on learners, for example as a result of cues. More objective measures of cognitive load such as dual-task methodology (see Brünken, Plass, & Leutner, 2003) are needed to support the assumptions concerning cognitive load when studying cued and uncued animations.

In sum, this dissertation has taken a closer look at cueing as a way to foster learning from animations with multiple simultaneous changes. The presented studies show that enhancing learning by cueing is not as simple as we initially thought and hence strategies have been identified that allow learners to benefit from the visual guidance offered by cues. Moreover, a framework has been developed that provides useful information about the instructional value of different types of cues and offers fertile grounds for future research endeavors. Furthermore, the combined use of performance-related measures (i.e., retention, transfer, mental effort scale) and process-related measures (i.e., eye tracking, verbal protocols) has yielded insights that could not have been gained by solely looking at learning outcomes alone. Thus, this dissertation presents a promising approach for the use, design, and study of cueing in animations that will hopefully be pursued in future research.

Chapter

9

Samenvatting en discussie

Het doel van dit proefschrift was om te onderzoeken of leren van een instructieve animatie met vele gelijktijdige veranderingen en zonder tekst kan worden versterkt wanneer de aandacht van de lerenden op relevante informatie in de animatie wordt gericht door visuele cues. Gebaseerd op de Cognitieve Belasting Theorie (Sweller, 1999) evenals het bestaande bewijs voor cueing in statische (b.v., tekst, afbeeldingen) en dynamische representaties (b.v., animaties), was de hypothese dat cueing (d.w.z., helderheidcontrast) de onnodige of ineffectieve cognitieve belasting die gepaard gaat met het zoeken naar relevante informatie in de animatie zou verminderen en daardoor het leren zou vergemakkelijken aangezien de vrijgemaakte werkgeheugenbronnen zouden kunnen worden besteed aan leergerelateerde activiteiten. In dit proefschrift werden zes studies gepresenteerd waarin de effectiviteit van visuele cues op het leren van een animatie van het cardiovasculaire systeem werd onderzocht. In Hoofdstukken 2, 3, en 4 werd onderzocht of cueing van specifieke delen van de animatie van het cardiovasculaire systeem een effectieve manier is om het leren van de animatie te bevorderen. Hoofdstuk 3 onderzocht of het aantal onderdelen in de animatie dat per tijdseenheid zou moeten worden verwerkt de effectiviteit van cueing beïnvloed en Hoofdstuk 4 onderzocht *hoe* cues de perceptuele en cognitieve verwerking van de animatie beïnvloeden. De studies gepresenteerd in Hoofdstukken 5 en 6 probeerden licht te werpen op de rol van verklaringen tijdens het leren van gecuede en niet gecuede animaties. In alle studies werd de betrokkenheid van cognitieve belasting onderzocht door te kijken naar geïnvesteerde mentale inspanning. In Hoofdstuk 7 werd de effectiviteit van cueing in animaties en statische representaties vergeleken en werd een framework voorgesteld voor de verschillende functies van cueing. In het huidige Hoofdstuk wordt een overzicht gegeven van de belangrijkste resultaten van de studies in dit proefschrift, zullen de theoretische en praktische implicaties van de bevindingen worden besproken, en worden er een aantal richtingen voor toekomstig onderzoek voorgesteld.

Overzicht van de belangrijkste bevindingen

Ondanks positieve resultaten van cueing op het leren van statische afbeeldingen en/of tekst (b.v., Kalyuga, Chandler, & Sweller, 1999; Lorch, 1989), hebben de eerste pogingen om cueing te onderzoeken in animaties geen verbeterd leren laten zien van een eenvoudige gecuede animatie (d.w.z., bestaande uit weinig onderdelen die tegelijkertijd zouden moeten worden verwerkt, Mautone & Mayer, 2001). De studie in **Hoofdstuk 2** onderzocht daarom of een cue die de aandacht van lerenden naar een belangrijk aspect van een complexe animatie (d.w.z., bestaande uit vele gelijktijdig gebeurende veranderingen) leidde, de ineffectieve cognitieve belasting verminderde en leren zou kunnen verbeteren. Deelnemers, die in twee groepen werden verdeeld, moesten de belangrijkste subsystemen van het cardiovasculaire systeem leren. Eén groep bestudeerde de animatie met een visuele cue op een enkel subsysteem van het cardiovasculaire systeem (d.w.z., het functioneren van de hartkleppen), terwijl de andere groep de animatie zonder de hulp van een dergelijke cue bestudeerde. Leeruitkomsten werden gemeten door te bekijken hoe de gecuede en de niet gecuede groepen retentie en transfervragen beantwoordden over zowel gecuede informatie als niet gecuede subsystemen van het cardiovasculaire systeem. Dit stelde ons in staat om vast te stellen wat de reikwijdte van cueing is, dat wil zeggen, of cueing enkel het begrip van gecuede informatie beïnvloedt en daarnaast of cueing van bepaalde aspecten in de animatie het begrip van niet gecuede aspecten belemmert. Na de animatie en na elke test, gaven deelnemers de hoeveelheid mentale inspanning die zij hadden geïnvesteerd aan op een 9-punts beoordelingsschaal (Paas, 1992). Er werd gevonden dat lerenden die de gecuede animatie bestudeerden betere retentie en transferresultaten hadden op zowel vragen over gecuede als niet gecuede informatie dan lerenden die de niet gecuede animatie bestudeerden. Echter, er werden geen rechtstreekse effecten van cueing op mentale inspanning gevonden. Er kan worden gesteld dat cueing werkgeheugenbronnen vrijmaakt die kunnen worden gebuikt voor activiteiten die lerenden helpen om gecuede en niet gecuede informatie beter te begrijpen. Cueing kan dus leren van de animatie versterken als gevolg van een effectiever gebruik van werkgeheugenbronnen.

De studie in **Hoofdstuk 3** gaat verder in op het cueing effect gevonden in Hoofdstuk 2 en testte, gebruikmakend van dezelfde materialen, of het effect van cueing op leren beïnvloed wordt door het aantal onderdelen dat per tijdseenheid in de animatie zou moeten worden verwerkt. Het aantal gelijktijdige veranderingen, en daarmee de cognitieve belasting die wordt opgelegd aan de lerenden, werd gemanipuleerd door de animatie op een hoge of een lage snelheid aan te bieden. De afspeelsnelheid van de gecuede en niet gecuede animaties was veel sneller of veel langzamer dan de afspeelsnelheid van de animatie in Hoofdstuk 2. Cognitieve belastingtheorie stelt dat met een toenemend aantal relaties die op hetzelfde moment verwerkt moeten worden, de noodzaak om snel de essentiële aspecten in een animatie te zoeken om in meer detail te verwerken, en daarmee de onnodige cognitieve belasting die hieraan gekoppeld is, ook groter wordt. Deze suggestie wordt ondersteund door enkele studies die cueing in statische representaties hebben onderzocht (b.v., Jeung, Chandler, & Sweller, 1997). Daarom werd verwacht dat cueing de ineffectieve cognitieve belasting ten gevolge van onnodig zoekgedrag zou verminderen en de leerprestatie zou verhogen als de animatie met een hoge afspeelsnelheid werd aangeboden, terwijl cueing minder noodzakelijk zou zijn voor het verminderen van ineffectieve cognitieve belasting en het verbeteren van het leren als de animatie met een lage afspeelsnelheid werd aangeboden. Tegen de verwachtingen in, konden lerenden die een gecuede animatie met een hoge of een lage afspeelsnelheid bestudeerden retentie en transfervragen over gecuede en niet gecuede informatie over het cardiovasculaire systeem even goed beantwoorden als lerenden die een niet gecuede animatie met een hoge of een lage afspeelsnelheid bestudeerden. Echter, lerenden die de animatie met een lage afspeelsnelheid bestudeerden besteedden meer tijd en investeerden meer mentale inspanning om deze prestatie te verkrijgen dan degenen die de animatie met een hoge afspeelsnelheid bestudeerden. Deze studie heeft dus niet het cueing effect gevonden dat werd verkregen in Hoofdstuk 2 en ondersteund daarmee niet het idee dat cueing voornamelijk effectief zou moeten zijn voor het verbeteren van leren van de animatie wanneer vele onderdelen tegelijkertijd verwerkt moeten worden. Deze bevindingen suggereren dat het noodzakelijk is om in meer detail te onderzoeken wat er eigenlijk exact gebeurt tijdens het leren van de animatie om cueing effectiever te kunnen gebruiken.

De bevindingen in Hoofdstuk 3 vormden de basis voor een diepgaandere analyse van de perceptuele en cognitieve processen die betrokken zijn bij het leren van gecuede en niet gecuede animaties. Daarom gebruikte de studie in **Hoofdstuk 4** dezelfde methodologie als de studie in Hoofdstuk 2, maar het design werd met proces-gerelateerde maten uitgebreid om licht te werpen op *hoe* mensen van de animatie van het cardiovasculaire systeem leren. Eye tracking werd gebruikt om de aandachtsverdeling over de onderdelen binnen de animatie te onderzoeken. Dit stelde ons bijvoorbeeld in staat om vast te stellen of cueing de aandacht van lerenden trekt of niet. Verder werd inzicht verkregen over welke cognitieve processen plaatsvonden tijdens het leren door lerenden achteraf te vragen om de gedachten die zij hadden tijdens het bestuderen van de animatie te rapporteren op basis van een opname van hun eigen oogbewegingen als activeringshint (d.w.z., cued retrospective reporting, Van Gog, Paas, van Merriënboer, & Witte, 2005). Een bijkomende doelstelling van deze studie was te onderzoeken of cueing effectiever zou zijn voor het leren als meerdere subsystemen van het cardiovasculaire systeem in de animatie zouden worden gecued in plaats van een enkel subsysteem te cue-en. Er werd verwacht dat lerenden langer en vaker zouden kijken naar gecuede dan naar niet gecuede onderdelen van de animatie. Verder werd verwacht dat visueel zoeken (d.w.z., ineffectieve belasting) zou worden verminderd. Bovendien werd verwacht dat de door cues vrijgekomen werkgeheugenbronnen lerenden de gelegenheid zouden geven om hun begrip van de inhoud, voornamelijk de gecuede informatie, te verbeteren wat teruggezien zou moeten worden in de verbale protocolgegevens alsmede de retentie en transfertests. Zoals verwacht keken lerenden vaker en voor langere tijdsperioden naar gecuede dan naar niet gecuede onderdelen van de animatie. Interessant is dat wanneer een enkel subsysteem van het hart werd gecued, de cues de aandacht in eerste instantie trokken, maar dat dit effect over de tijd verdween. Er werden echter geen effecten van cueing op mentale inspanning en visueel zoeken gevonden. Verder had cueing slechts een kleine invloed op de cognitieve verwerking van de lerenden zoals bleek uit de retrospectieve verbale protocollen. Lerenden die de animatie met een enkele cue bestudeerden genereerden meer correcte verklaringen over het gecuede onderdeel dan lerenden die de animatie zonder cues bestudeerden. Tegen de verwachtingen in leidde het bestuderen van een animatie met meerdere cues niet tot diepere cognitieve verwerking dan het bestuderen van een animatie met een enkele cue of zonder cues. Bovendien, gelijk aan de resultaten van Hoofdstuk 3, leidde cueing niet tot hogere scores op retentie en transfervragen over de gecuede en niet gecuede onderdelen van het cardiovasculaire systeem. Deze bevindingen suggereren dat cues op effectieve wijze de aandacht van lerenden naar specifieke locaties in een animatie kunnen leiden, maar cues garanderen niet dat de conceptuele relaties tussen de verschillende componenten van het cardiovasculaire systeem geïdentificeerd worden (zie ook Kriz & Hegarty, 2007). Daarom wordt geconcludeerd dat aandachtrichtende cues lerenden helpen om relevante informatie uit animaties te halen, maar zulke cues lijken voor lerenden niet voldoende te zijn om zich spontaan bezig te houden met actieve kennisbouwactiviteiten. Om de kans te vergroten dat cueing een effect heeft op conceptueel begrip is het daarom wellicht belangrijker om lerenden te ondersteunen in het concentreren van hun geïnvesteerde mentale inspanning op leren-gerelateerde activiteiten (d.w.z., effectieve belasting, Paas, Renkl, & Sweller, 2003) in plaats van slechts te proberen het ontwerp van de animatie te verbeteren.

Nadat we vastgesteld hadden dat cueing voornamelijk de perceptuele verwerking van de lerenden beïnvloedde en niet zozeer hun cognitieve verwerking (zie Hoofdstuk 4), richtten Hoofdstuk 5 en 6 zich op het stimuleren van de interne kennisbouwprocessen van de lerenden om de gepresenteerde informatie actief te verwerken en de mogelijkheid te vergroten om een cueing effect op conceptueel begrip te verkrijgen. In de studie beschreven in **Hoofdstuk 5**, moesten lerenden een animatie van het cardiovasculaire systeem onder één van vier experimentele condities bestuderen. Eén groep bestudeerde de animatie waarin alle subsystemen van het cardiovasculaire systeem opeenvolgend werden gecued terwijl lerenden aangespoord werden om hardop voor zichzelf te verklaren waarom de bewegingen en veranderingen van de onderdelen in de animatie gebeurden. Een tweede groep bestudeerde de animatie zonder cues, maar lerenden werden nog steeds aangespoord zelfverklaringen te genereren tijdens de animatie. De derde en vierde groepen bestudeerden of een gecuede of een niet gecuede animatie van het cardiovasculaire systeem, maar werden niet aangespoord zelfverklaringen te genereren terwijl zij de animatie bekeken. Er werd gesteld dat alleen als de animatie cues bevatte die de werkgeheugenbelasting die gepaard gaat met het zoeken naar specifieke onderdelen verminderde, lerenden voldoende werkgeheugenbronnen beschikbaar zouden hebben voor het maken van de oorzakelijke relaties die fundamenteel zijn voor het ontwikkelen van een geïntegreerde mentale representatie van de animatie. Daarom werd verwacht dat het leren van een gecuede animatie zou worden verbeterd door zelfverklaringen te genereren terwijl zelfverklaren met een niet gecuede animatie leren niet zou verbeteren. Anderzijds kan worden gesteld dat door verschillende subsystemen van het cardiovasculaire systeem opeenvolgend te cue-en, een gestructureerde opeenvolging van zinvolle functionele onderdelen aan lerenden wordt gegeven die zij kunnen gebruiken om hun zelfverklaringactiviteiten te organiseren. Verder werd het ook voorspeld dat zelfverklaren met een gecuede animatie betekenisvollere soorten zelfverklaringen zou moeten ontlokken dan zelfverklaren met een niet gecuede animatie. Zoals voorspeld, gaven de resultaten aan dat, vergeleken met de andere drie groepen, de lerenden die zelfverklaarden met een gecuede animatie hogere scores hadden op retentie, inferentie en transfertests. Er werden geen verschillen gevonden tussen de drie andere groepen. Verder rapporteerden alle vier de groepen een gelijke hoeveelheid geïnvesteerde mentale inspanning. Gebaseerd op cognitieve belastingtheorie zou er nog steeds kunnen worden gesteld dat vergeleken met alle andere groepen, de gecuede zelfverklaringgroep hun werkgeheugenbronnen het efficiëntst gebruikt hebben, wat werd ondersteund door een analyse op de efficiëntiescores. Verder toonde de inhoud van de zelfverklaringen aan dat, in lijn met de voorspellingen, cueing betekenisvollere soorten zelfverklaringen ontlokte die vervolgens positief samenhingen met de testscores op alle leeruitkomstmaten. Deze bevindingen suggereren dat zelfverklaren effectief kan worden uitgebreid van het begrip van teksten en/of statische afbeeldingen (Ainsworth & Loizou, 2003; Slager, 2006) naar leren van gecuede animaties om het leren van de onderliggende principes en relaties van een dynamisch systeem te stimuleren. Aan de andere kant kan zelfverklaren met een niet gecuede animatie waarin lerenden niet hun cognitieve verwerking kunnen richten op specifieke delen van de animatie, het vormen van een samenhangende mentale representatie belemmeren (Renkl & Atkinson, 2007).

Terwijl de studie in Hoofdstuk 5 de effectiviteit van cueing probeerde te verbeteren door lerenden aan te sporen om zelfverklaringen te genereren over het functioneren van het cardiovasculaire systeem, onderzocht de studie gerapporteerd in **Hoofdstuk 6** of het leren van een gecuede animatie verder zou kunnen worden verbeterd als de verklaringen niet door de lerende worden gegenereerd, maar aan de lerende worden gegeven in een gesproken tekst bij de animatie. Zoals in Hoofdstuk 5, genereerde één groep zelfverklaringen terwijl een gecuede animatie werd bestudeerd en een tweede groep genereerde zelfverklaringen met een niet gecuede animatie. Bovendien was er een derde en een vierde groep die of een gecuede of een niet gecuede animatie bestudeerden die beide voorzien waren van een gesproken tekst die de cruciale relaties beschreef die werden getoond in de animatie van het cardiovasculaire systeem. Er werd verwacht dat het genereren van zelfverklaringen en het ontvangen van verklaringen de leerresultaten zouden verbeteren als lerenden een gecuede animatie bestudeerden, maar niet als zij een niet gecuede animatie bestudeerden, omdat beide cognitieve activiteiten een aanzienlijke hoeveelheid van de werkgeheugenbronnen vereisen om de meest cruciale relaties uit de animatie te halen en te verwerken. Verder kan zelfverklaren gemakkelijk leiden tot fouten en verkeerde inferenties terwijl verklaringen gegeven in een gesproken tekst correcte informatie communiceren. Daarom werd het ook verwacht dat lerenden die een animatie met gesproken tekst bestudeerden beter zouden scoren dan degenen die zelfverklaringen moesten genereren tijdens de animatie. De resultaten lieten zien dat, zoals voorspeld, het genereren van zelfverklaringen en het ontvangen van verklaringen tot een verbeterde retentie, inferentie en transferprestatie leidde wanneer een gecuede in plaats van een niet gecuede animatie werd bestudeerd. Verder, ongeacht cueing, verbeterden verklaringen alleen het aantal correcte inferenties op de inferentietest vergeleken met de zelfverklaringsconditie. Bovendien werden er geen resultaten op geïnvesteerde mentale inspanning gevonden. Deze bevindingen suggereren dat alleen het stimuleren van lerenden om de animatie van het cardiovasculaire systeem actief te verwerken door het genereren van zelfverklaringen of het aan de lerenden geven van de belangrijkste principes en onderliggende relaties van het cardiovasculaire systeem in de vorm van een gesproken tekst niet noodzakelijk leidt tot verschillen in leerresultaten. Het lijkt eerder zo dat het essentieel is dat de animatie wordt ondersteund door cues, zodat lerenden hun constructieve activiteiten op de essentiële aspecten van de animatie kunnen richten.

Tenslotte, in **Hoofdstuk 7**, werd een bredere context van cueing voorgesteld om licht te werpen op de overeenkomsten en verschillen tussen de perceptuele en cognitieve consequenties van cueing in het leren van statische en dynamische representaties. Een framework werd ontwikkeld voor het classificeren van drie verschillende functies van cueing, die worden ondersteund door een aanzienlijk aantal studies over het effect van cueing op het begrijpen van tekst en/of statische illustraties: 1) cues richten aandacht op specifieke schermlocaties (d.w.z., selecteren), 2) cues benadrukken de structuur van educatieve materialen (d.w.z., organiseren), en 3) cues maken relaties binnen en tussen onderdelen explicieter (d.w.z., integratie). Dit framework werd gebruikt om het beschikbare onderzoek naar cueing in animaties (inclusief de studies beschreven in Hoofdstuk 2, 3 en 4) in een bredere context te evalueren en te bespreken. Het overzicht bracht aan het licht dat cues die de aandacht op specifieke aspecten van animaties richten, de aandacht effectief leiden naar de gecuede delen net zoals zulke cues in statische representaties doen, maar dat deze cues veel minder effectief zijn in het helpen om de noodzakelijke oorzakelijke relaties eruit te halen dan in statische materialen. Verder, in tegenstelling tot statische representaties, lijken cues die de relaties binnen en/of tussen onderdelen benadrukken en cues die de organisatie structuur van een onderwerp naar voren halen niet conceptueel begrip in animaties te verbeteren (maar zie Hoofdstuk 6). Enkele redenen waarom succesvolle benaderingen van cueing in het leren van statische representaties niet het leren van animaties lijken te verbeteren worden voorgesteld, waaronder de suboptimale manier waarop cues zijn onderzocht in animaties, de dynamische kenmerken van animaties, en het gebrek aan geëngageerdheid van de lerenden met cues. Verder werden praktische en theoretische implicaties besproken en er werd geconcludeerd dat benaderingen van cueing zouden moeten worden ontwikkeld die werken in animaties in plaats van het onkritisch toepassen van benaderingen van cueing die succesvol zijn gebleken in het leren van statische representaties.

Discussie en conclusie

De studies beschreven in dit proefschrift werden opgezet om te onderzoeken of cueing een effectieve manier is voor het versterken van leren van een animatie met meerdere gelijktijdig gebeurende veranderingen. Gebaseerd op de cognitieve belastingtheorie, was de hypothese dat cueing visueel zoeken en de daarmee gepaarde ineffectieve cognitieve belasting zou verminderen en leren van de animatie zou verbeteren. In deze sectie zullen de belangrijkste bevindingen van dit proefschrift nader worden bekeken en zullen de resultaten in het licht van het belangrijkste theoretische kader en de hypothesen die daaruit voortvloeien worden besproken.

De resultaten van de studies in dit proefschrift geven aan dat voor het verbeteren van het begrip van informatie betreffende verandering over tijd via een instructieve animatie, het niet voldoende is om eenvoudigweg enkele of meerdere visuele cues aan een animatie toe te voegen. In vier studies (Hoofdstukken 2, 3, 4, en 5) werd een rechtstreekse vergelijking gemaakt tussen het leren van een gecuede en een niet gecuede animatie zonder tekstuele verklaringen, maar alleen in één van deze studies (Hoofdstuk 2) leidde het bestuderen van een gecuede animatie tot betere leerprestaties dan het bestuderen van een niet gecuede animatie. Dit verschaft geen bewijs dat het richten van aandacht met cues in een instructieve animatie tot beter leren leidt dan het bestuderen van de animatie zonder cues. Het is nog onduidelijk onder welke omstandigheden cueing in een animatie zonder tekst het leren zou kunnen versterken. In onze studies was het effect van cueing op het begrip van de animatie in de lerenden betrekkelijk klein. Echter, wij hebben slechts één type cueing (d.w.z., helderheidcontrast) bestudeerd in één soort animatie (d.w.z., cyclische animatie). Verder onderzoek met verschillende soorten animaties en met verschillende typen van cueing is vereist om vast te stellen wat het effect van cueing op het leren van animaties is.

Verder werd in geen van de studies in dit proefschrift bewijs gevonden voor verminderde cognitieve belasting als gevolg van cues. Bovendien werd, zoals rechtstreeks in Hoofdstuk 4 is aangetoond, visueel zoeken ook niet verminderd. Daarnaast liet de studie in Hoofdstuk 4 zien dat visuele cues alleen effectief de perceptuele verwerking beïnvloeden door de aandacht van de lerende op specifieke delen van een animatie te richten, maar verder niet de cognitieve verwerking van de afgebeelde inhoud garanderen. Daarom lijken signalen noodzakelijk voor het letten op de juiste informatie, maar zij zijn onvoldoende voor een beter begrip van deze informatie. Dus in de meerderheid van de studies in de Hoofdstukken 2 tot en met 5 werd geen steun gevonden voor de hypothese dat cueing alleen het leren van een animatie verbetert. Dit suggereert dat cueing, in plaats van rechtstreeks het leren van animaties te beïnvloeden, waarschijnlijker een 'enabling' functie heeft in het leerproces. Dat wil zeggen, cueing kan gestructureerde sturing geven naar relevante delen van een animatie die kan dienen als invoer voor een verdere uitgebreide manier van verwerking van de aangeboden informatie.

Gebaseerd op deze bevindingen werd een tweede hypothese onderzocht, namelijk dat als de cognitieve verwerking aan de kant van de lerende zou worden bevorderd in een animatie, de effectiviteit van cueing voor het ontwikkelen van een grondiger begrip van een animatie en de kansen van kennisoverdracht zouden worden vergroot. De studies in Hoofdstukken 5 en 6 verschaffen bewijs dat zowel het aansporen van lerenden om zelfverklaringen te genereren over het functioneren van het cardiovasculaire systeem als het verwerken van gesproken tekst die de animatie begeleidt en waarin de functionele relaties van het cardiovasculaire systeem worden beschreven leren versterkt, tenminste wanneer de animatie gecued wordt. Het begrip van de lerenden werd alleen verbeterd door het geven van cues die de aandacht van de lerende stuurde en hen in staat stelde om betekenisvolle zelfverklaringen te genereren of een rechtstreekse verbinding vormde tussen de gesproken tekst en de animatie. Het begrip van de lerenden van de niet gecuede animatie werd niet verbeterd door slechts het genereren van zelfverklaringen of het actief verwerken van de gesproken tekst die de animatie begeleidde. Het feit dat betere leerprestatie werden verkregen in de gecuede dan in de niet gecuede condities zonder verschillen in totale cognitieve belasting suggereert dat lerenden in de gecuede conditie hun werkgeheugenbronnen effectiever gebruikten dan degenen in de niet gecuede conditie. Dus, in overeenstemming met de waarneming dat alleen cueing het leren niet ondersteunt, leidt het eenvoudigweg aanmoedigen van constructieve cognitieve verwerkingsactiviteiten in lerenden niet noodzakelijk tot verbeterd leren in animaties, maar lijkt leren alleen te worden verbeterd als de constructieve activiteiten met cues worden ondersteund.

Daarom is een belangrijke conclusie van de studies in dit proefschrift dat perceptuele en cognitieve verwerking beschouwd zouden kunnen worden als afzonderlijke aspecten van het leerproces, tenminste voor de animatie gebruikt in onze studies, maar dat beide aspecten zouden moeten worden ondersteund om een nauwkeurige conceptuele representatie van de afgebeelde informatie te bereiken. Cueing verbetert leren van een animatie alleen op een effectieve manier als lerenden ook bezig zijn met constructieve activiteiten. Aan de andere kant, bezig zijn met betekenisvolle leeractiviteiten leidt alleen tot dieper begrip als cues lerenden de gelegenheid geven deze activiteiten op een dergelijke manier uit te voeren dat hun cognitieve activiteiten worden gericht op de essentiële delen van de animatie (Renkl & Atkinson, 2007). Dus de combinatie van cues om de perceptuele verwerking van lerenden te vergemakkelijken en de actieve cognitieve verwerkingsstrategieën om cognitieve verwerking in lerenden aan te moedigen lijkt een zeer effectieve educatieve combinatie voor het verbeteren van leren van animaties. Als cueing wordt weggelaten van het ontwerp van animaties of als lerenden niet bezig zijn met verwerkingsactiviteiten om de functionele relaties van de animatie te begrijpen, is het niet waarschijnlijk dat leren van animaties verbeterd wordt.

Theoretische implicaties

De bevindingen van dit proefschrift hebben een aantal implicaties voor de theoretische benadering van het cueing effect in animaties zoals gegeven door dominante theorieën van multimedialeren en educatief ontwerp zoals de theorieën van Sweller (1999) en Mayer (2001).

In theorieën zoals de cognitieve belastingtheorie van Sweller en Mayer's theorie van multimedialeren wordt aangenomen dat een cueing effect voorkomt omdat het werkgeheugen effectiever wordt gebruikt als de aandacht op relevante aspecten van de educatieve materialen wordt gericht en daardoor de ineffectieve cognitieve belasting die gepaard gaat met het zoeken naar informatie wordt verminderd om cognitieve bronnen beschikbaar te hebben voor de verdere verwerking van relevante informatie. Gebaseerd op deze redenering, kan de cognitieve belastingtheorie veel van de gerapporteerde resultaten uitleggen door te stellen dat de bijdrage van de verschillende typen belasting door cues is veranderd zonder de totale cognitieve belasting te beïnvloeden. Dat wil zeggen, de cues kunnen hebben geleid tot een substitutie van ineffectieve naar effectieve cognitieve belasting, omdat de investering van mentale inspanning op essentiële activiteiten (d.w.z., effectieve belasting) wordt gericht zonder bezig te hoeven zijn met irrelevante activiteiten (d.w.z., ineffectieve belasting). Drie van de studies in dit proefschrift (Hoofdstukken 2, 5, en 6) ondersteunen een dergelijke cognitieve belastingverklaring van cueing op leren door aan te tonen dat gegeven gelijke hoeveelheden van cognitieve belasting voor de gecuede en de niet gecuede condities, het bestuderen van een gecuede animatie in betere leerprestaties resulteerde dan het bestuderen van een niet gecuede animatie. In deze studies lijken lerenden dus hun werkgeheugenbronnen effectiever te hebben gebruikt door cues.

Echter, niet al onze bevindingen, voornamelijk die waarin leerresultaten niet werden verbeterd door cueing, kunnen door een dergelijke substitutieverklaring worden uitgelegd. In drie studies (Hoofdstukken 3, 4, en 5) rapporteerden lerenden gelijke hoeveelheden mentale inspanning ondanks het feit dat er geen verschillen in leerprestaties werden gevonden tussen gecuede en niet gecuede animaties zonder verklaringen. Het feit dat er geen verlaging in cognitieve belasting werd gevonden kan erop duiden dat het type cueing gebruikt in onze studies niet echt cognitieve belasting heeft beïnvloed en daarom werden geen verschillen gerapporteerd. Echter, zoals hierboven besproken, werd in sommige studies bewijs gevonden dat de cues tot een effectievere investering van mentale inspanning hebben geleid, dus het is onduidelijk waarom cognitieve belasting in de studies gerapporteerd in Hoofdstukken 3, 4, en 5 niet werd verminderd. Bovendien rapporteerde de studie in Hoofdstuk 3 zelfs cognitieve belastingresultaten die leken in te gaan tegen de voorspellingen van de cognitieve belastingtheorie of er niet door konden worden verklaard.

Het is belangrijk om te bedenken dat verklaringen en veronderstellingen over elk type van cognitieve belasting niet rechtstreeks kunnen worden getest, omdat er tot op heden geen meetinstrumenten zijn om direct onderscheid te maken tussen de drie verschillende typen cognitieve belasting, te weten intrinsieke, ineffectieve en effectieve belasting. Aangezien sommige van de studies in dit proefschrift meer dan één type cognitieve belasting tegelijkertijd hebben gemanipuleerd en cueing verschillende belastingtypen samen zou kunnen hebben beïnvloed (d.w.z., afname van ineffectieve en toename van effectieve belasting), kunnen definitieve conclusies aangaande de rol van cognitieve belasting en de haalbaarheid van cognitieve belasting-gerelateerde verklaringen niet worden getrokken. Niettemin suggereren de bevindingen in dit proefschrift dat het belangrijk is om experimentele ontwerpen te gebruiken en/of cognitieve belastingmaten te ontwikkelen die het mogelijk maken om individuele bijdragen van elk belastingtype te identificeren en alternatieve verklaringen te testen om meer inzicht te krijgen in de precieze rol die cognitieve belasting speelt in het leren en zo cognitieve belasting theorie-gebaseerde hypothesen effectiever te kunnen testen.

Er kan worden gesteld dat een verklaring van cueing die zich hoofdzakelijk concentreert op cognitieve factoren onbevredigend is in het verklaren van de effecten van cueing op de verwerking van animaties, maar ook perceptuele dimensies zou moeten beschouwen. In Hoofdstuk 4 werd bijvoorbeeld aangetoond dat cueing voornamelijk betrokken is bij vroege perceptuele processen en weinig of slechts een kleine invloed heeft op de cognitieve verwerking van lerenden. Deze bevinding wordt ondersteund door onderzoek dat de effectiviteit van pijl-cues op het begrip van een mechanisch systeem onderzocht (d.w.z., spoelreservoir van een toilet, Kriz & Hegarty, 2007) en lijkt daarom te gelden voor verschillende typen van cueing en voor verschillende animaties. Bovendien zijn zulke specifieke resultaten van cues op leren niet beperkt tot animaties, maar worden ze soms ook gerapporteerd in onderzoek naar cueing om de verwerking van tekst te vergemakkelijken (Lorch, 1989). Ondanks het feit dat zowel cognitieve belastingtheorie als Mayer's theorie van multimedialeren zich hoofdzakelijk baseren op werkgeheugenbeperkingen, worden sommige verklaringen en bevindingen die zijn voortgevloeid uit deze theorieën zoals het split-attention effect (Sweller et al., 1998) gebaseerd op perceptuele en aandachtsfenomenen. In lijn hiermee, suggereren de resultaten van dit proefschrift dat perceptuele aspecten als een (meer) essentieel aspect van cognitieve belastingtheorie en Mayer's theorie van multimedialeren zouden moeten worden behandeld om specifieke voorspellingen te maken en om de resultaten van cueing op leren volledig te kunnen verklaren.

De resultaten van de studies in dit proefschrift suggereren ook dat een ander aspect, namelijk een gedetailleerde uiteenzetting van de processen die precies tijdens het leren gebeuren, vereist is in theorieën die er op gericht zijn perceptuele en cognitieve verwerking in animaties te verklaren. Hoewel huidige theorieën op het gebied van leren en instructie zoals cognitieve belastingtheorie en Mayer's theorie van multimedialeren zich hoofdzakelijk hebben beziggehouden met leeruitkomsten, hebben enkele recente studies waarin deze theorieën het belangrijkste theoretische kader vormden, geprobeerd de onderliggende processen van het leren van dynamische systemen via animaties en statische afbeeldingen te achterhalen (Scheiter & Van Gog, in druk). Niettemin, inzichten van andere velden zoals het domein van tekstbegrip, waarin er een tamelijk goed begrip is van hoe lerenden een grondiger begrip van dynamische systemen bereiken, zou meer kennis kunnen geven over wat leren van animaties inhoudt om effectievere animaties te ontwerpen en om cognitieve belastingtheorie en Mayer's theorie van multimedialeren verder te verbeteren. In Hoofdstukken 5 en 6 werd een bredere benadering genomen door instructietechnieken van tekstbegriponderzoek waarvan bekend is dat ze het begrip van de lerenden verbeteren, zoals het zelfverklaren, te introduceren. De informatie van de tekstbegripliteratuur bleek nuttiger te zijn dan cognitieve belastingtheorie voor de formulering van specifieke en gedetailleerde hypotheses en voor het verzorgen van een geschikte theoretische verklaring van de bevindingen, zoals waarom het genereren en ontvangen van verklaringen met een animatie tot dezelfde transferprestaties hebben geleid (Hoofdstuk 6). Het zou dus kunnen worden gesteld dat een multidisciplinair perspectief nodig is om huidige theorieën van cognitie en leren zoals cognitieve belastingtheorie te verbeteren en te verfijnen door te bouwen op theorieën en eerder onderzoek uit verschillende disciplines en/of onderzoekstradities (cf. Ayres & Paas, 2009). Het is bijvoorbeeld reeds aangetoond dat belangrijke inzichten van belichaamde of gegronde theorieën van cognitie (voor een overzicht, zie Barsalou, 2008) effectief kunnen worden gebruikt om de cognitieve belastingtheorie te verrijken om effectieve animaties te ontwerpen (Ayres, Marcus, Chan, & Qian, 2009). Volgens belichaamde theorieën worden mentale representaties van zelfs abstracte kennis in zintuiglijke ervaringen gegrond, zodat verwerken van deze representaties een zekere vorm van zintuiglijke simulatie omvat. Zelfs voor het leren van de dynamica van abstracte dynamische systemen, zouden belichaamde theorieën voorspellen dat de bewegingen van het afgebeelde systeem zouden kunnen worden begrepen door het maken van die beweging.

Onze bevindingen hebben ook een aantal specifiekere implicaties voortgebracht voor theorieën en bevindingen in het veld van tekstbegrip. In Hoofdstukken 5 en 6 werd laten zien dat zelfverklaren niet alleen een effectieve strategie is voor het verbeteren van het begrip van de lerende van dynamische systemen via teksten (Chi, de Leeuw, Chiu, & LaVancher, 1994), diagrammen (Ainsworth & Loizou, 2003) en tekst en afbeeldingen (Butcher, 2006) maar ook via animaties zonder tekst. Deze bevinding suggereert dat andere strategieën van tekstbegriponderzoek die erop zijn gericht om het begrip van dynamische systemen in lerenden te verbeteren, zoals reflectie op geleerde informatie, ook effectief zouden kunnen worden gebruikt om leren van (gecuede) animaties over dynamische systemen te versterken.

Praktische implicaties

Behalve theoretische implicaties volgen er ook een aantal praktische implicaties uit de resultaten van de studies gepresenteerd in dit proefschrift. Zoals duidelijk is geworden, leidt kijken naar een instructieve animatie zonder gesproken en geschreven tekst die vele gelijktijdige veranderingen bevat niet noodzakelijk tot het leren van het functioneren van het afgebeelde systeem. Niettemin kunnen deze animaties een effectieve manier zijn voor het onderwijzen over begrippen van verandering, op voorwaarde dat zowel de perceptuele als de cognitieve verwerking van de lerende ondersteund worden. Zoals de studies in dit proefschrift aantonen, is een manier om deze steun te bewerkstelligen de animaties te verrijken met cues die lerenden helpen om op de relevante delen van de inhoud te richten, vooral als dit met activiteiten wordt gecombineerd die lerenden actief aanmoedigen om de informatie in de animatie dieper te verwerken zoals het genereren van verklaringen over het functioneren van het afgebeelde systeem of functionele verklaringen van andere leerlingen of experts te bestuderen.

De bevindingen in dit proefschrift suggereren ook dat, hoewel het bevorderen van cognitieve verwerking zou moeten gebeuren in combinatie met cues in de animatie, er meerdere wegen zijn om lerenden te helpen om op een effectieve manier de cruciale informatie van animaties dieper te verwerken om een nauwkeurig begrip van de animatie te ontwikkelen. Het geven van de cruciale kennis over het systeem afgebeeld in de animatie via gesproken tekst bleek even effectief te zijn als lerenden de informatie zelf te laten produceren. In het licht van de kansen van implementatie in het onderwijs lijkt de eerste strategie het meest geschikt omdat het meer gestructureerd is en gemakkelijker kan zijn om in een echt klaslokaal uit te voeren. Bijvoorbeeld, een biologieleraar kan het functioneren van het cardiovasculaire systeem uitleggen terwijl tegelijkertijd een animatie van dit systeem op een digitaal scherm naast de leraar wordt afgespeeld waarin de onderdelen die de leraar uitlegt worden uitgelicht door ze te cue-en.

Verder, het functionele framework voor cueing voorgesteld in Hoofdstuk 7 kan ook belangrijke implicaties hebben voor wanneer en hoe cueing te gebruiken in instructieve animaties. Het framework biedt een nuttige classificatie voor de verschillende functies van cueing en geeft gedetailleerde informatie over de precieze rol van verschillende soorten cues. Dit kan leraren en ontwerpers van instructie helpen in het beslissen om cueing al of niet te gebruiken in animaties en het type cueing af te stemmen op de doelen van instructie om lerenden te helpen een specifiek leerdoel te bereiken. Bijvoorbeeld, het framework suggereert dat cues alleen aandacht kunnen richten en daarom zouden ze gecombineerd moeten worden met constructieve activiteiten als het leerdoel is om het begrip van een animatie te verbeteren. Het framework en de bevindingen die het heeft opgeleverd of zal opleveren in toekomstig onderzoek, voorziet leraren en ontwerpers van instructie van een toenemende kennisbasis die hen toestaat om geïnformeerde beslissingen te maken over welke cues in welke situaties en onder welke omstandigheden zouden moeten worden gebruikt om animaties effectief te gebruiken als educatieve materialen.

Aanbevelingen voor vervolgonderzoek

De studies die besproken worden in dit proefschrift weerspiegelen een betrekkelijk recente lijn van onderzoek in het leren van animaties en de onderwijspsychologie. Hoewel enkele jaren geleden de studies naar cueing in animaties zeldzaam waren, zijn er inmiddels een aantal studies in de literatuur terug te vinden die cueing in animaties hebben onderzocht (b.v., Boucheix & Lowe, in druk; Kriz & Hegarty, 2007). Desalniettemin zijn er vele aspecten op dit gebied die nog onderzocht moeten worden. De meerderheid van studies die de effecten van cueing op de verwerking van animaties hebben onderzocht hebben alleen cues onderzocht die tot doel hadden om de aandacht van de lerende op specifieke locaties in animaties te richten (inclusief Hoofdstukken 2, 3, 4, 5). Echter, zoals reeds aangegeven in het functionele framework gepresenteerd in Hoofdstuk 7, kan cueing ook de functies dienen om de organisatie van de inhoud te benadrukken en om lerenden bewust te maken van onderdelen die gerelateerd zijn binnen en/of tussen representaties. Om de educatieve effectiviteit van cueing in animaties verder te onderzoeken en om het volledige spectrum van functies te bedekken, is onderzoek nodig dat zich concentreert op of en hoe organisatorische en relationele cues het leren van animaties met en zonder tekst beïnvloeden.

Bovendien moeten sommige aspecten van de studies gerapporteerd in dit proefschrift verder worden onderzocht of bevestigd worden door verder onderzoek om definitieve uitspraken over de aandachtssturende functie van cueing te maken. Een belangrijk aspect in dit opzicht betreft de generaliseerbaarheid van de gerapporteerde bevindingen. Bijvoorbeeld, de gepresenteerde studies werden met alleen één cyclische animatie uitgevoerd die een oorzaak-gevolgsysteem toonde en systeem-gestuurd werd aangeboden zonder tekstuele verklaringen (behalve Hoofdstukken 5 en 6). Bovendien, alleen één type cueing, namelijk spotlight-cueing, werd gebruikt, die wel of niet kan worden gegeneraliseerd naar andere typen cueing zoals pijlen. Aan de ene kant, enkele van deze aspecten zoals het hoofdzakelijk perceptuele effect van spotlight-cueing, kan breder worden veralgemeniseerd, aangezien overeenkomende bevindingen zijn verkregen die in lijn zijn met eerder onderzoek (Kriz & Hegarty, 2007). Bovendien konden de bevindingen ook worden gerepliceerd van een laboratorium naar een klaslokaal en van universiteitsstudenten naar middelbare scholieren. Deze aanwijzingen bieden wat geloofwaardigheid aan de robuustheid van de geobserveerde bevindingen. Aan de andere kant, zou verder onderzoek dat de beperkingen van onze studies aanpakt, bijvoorbeeld met verschillende soorten animaties, verschillende soorten cues en andere soorten leerlingen onze conclusies verder kunnen versterken.

Verder hebben de gepresenteerde studies begrip en transfer van verworven kennis getest, maar de tests werden alleen rechtstreeks na de experimenten afgenomen. Vanuit een onderwijsperspectief zou het interessant zijn om te onderzoeken of en in hoeverre de geleerde informatie wordt geconsolideerd en bruikbaar blijft na langere tijdsperiodes. Dit kan voornamelijk relevant zijn als men meer inzicht wil verkrijgen in de precieze processen van het leren van gecuede en niet gecuede animaties, zoals hoe leren door te genereren (d.w.z., zelfverklaren) of ontvangen van verklaringen (d.w.z., gesproken tekst) van elkaar verschillen (zie Hoofdstuk 6). Onderzoek naar het testing effect, bijvoorbeeld, heeft reeds aangetoond dat actief terughalen of genereren van informatie resulteert in betere lange termijn herinneringsprestaties vergeleken met het lezen of horen van de informatie (Roediger & Karpicke, 2006). Toekomstig onderzoek zou daarom ook rekening moeten houden met lange termijn testen van verworven kennis.

Een ander aspect dat verder onderzoek vereist is de precieze rol van cognitieve belasting in het bestuderen van gecuede en niet gecuede animaties. Hoewel het gebruik van zelfrapportage beoordelingsschalen een betrouwbare indicatie geeft van de relatieve verschillen in cognitieve belasting, biedt het geen rechtstreekse informatie over de typen van cognitieve belasting die aan lerenden wordt opgelegd, bijvoorbeeld door cues. Objectievere meetinstrumenten van cognitieve belasting zoals dual-task methodologie (zie Brünken, Plass, & Leutner, 2003) zijn nodig om de veronderstellingen aangaande cognitieve belasting tijdens het bestuderen van gecuede en niet gecuede animaties te ondersteunen.

Samengevat, dit proefschrift heeft nader gekeken naar cueing als een manier om het leren van animaties met meerdere gelijktijdige veranderingen te ondersteunen. De gepresenteerde studies laten zien dat het versterkten van leren door cueing niet zo eenvoudig is als wij in eerste instantie dachten en daarom zijn strategieën geïdentificeerd die lerenden in staat stellen om te kunnen profiteren van het voordeel van de visuele sturing die cues bieden. Bovendien is een framework ontwikkeld dat nuttige informatie biedt over de educatieve waarde van verschillende soorten cues en vruchtbare terreinen voor toekomstige onderzoekspogingen voorstelt. Verder hebben het gecombineerde gebruik van prestatie-gerelateerde meetinstrumenten (d.w.z., retentie, transfer, mentale inspanningsschaal) en proces-gerelateerde meetinstrumenten (d.w.z., eye tracking, verbale protocollen) inzichten opgeleverd die door alleen te kijken naar leerresultaten niet bewerkstelligd hadden kunnen worden. Dus, dit proefschrift presenteert een veelbelovende benadering voor het gebruik, ontwerp en studie van cueing in animaties waar hopelijk in toekomstig onderzoek een vervolg aan zal worden gegeven.

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Appendices

Appendix A

Checklist of prior knowledge of the cardiovascular system

1-item Self-Rating

How much knowledge do you have about the cardiovascular system?

1	2	3	4	5
very little	little	not little, not much	much	very much

4-item Checklist

Did you take biology classes in your final exam in high school?

☐ Yes

☐ No

In high school I took biology classes on the following level:

☐ I did not take biology classes

☐ Biology 1

☐ Biology 2

☐ Biology 1 and 2

I have taken biology classes after high school.

☐ Yes

☐ No

I know someone from my inner circle who has suffered from a heart condition or has had a treatment to prevent it during the last 5 years.

☐ Yes

☐ No

Appendix B

Sample retention/comprehension, inference, and transfer questions for each category

a - Valves system

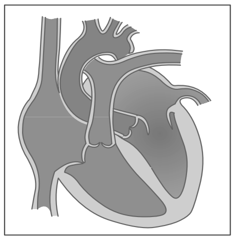
When this valve, as indicated on the picture is open, then...

a) blood flows from the undermost compartment to the uppermost compartment of the heart

b) blood flows to the lungs

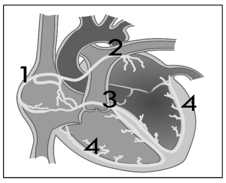
c) blood flows from the uppermost compartment to the undermost compartment of the heart

d) blood flows into the body

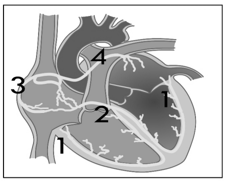


b - Electrical system

Which picture shows the course of the electrical system correctly?



a)



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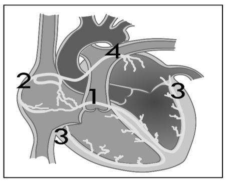
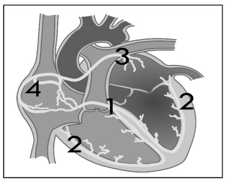


c)



d)

c - Pulmonary circulation

Blood enters the heart from the body. How many times does the heart contract before blood enters the lungs?

a) 1

b) 2

c) 3

d) 4

d - Circulatory system

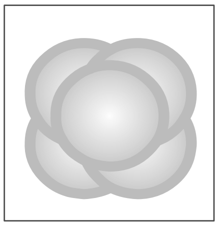
Do the pulmonary alveoli (see picture) change colors?

a) yes, with every contraction of the heart

b) yes, with the storage and release of oxygen

c) no, the pulmonary alveoli only get bigger

d) no, the pulmonary alveoli stay the same



e - Systemic circulation

How does blood travel from the left side of the heart to the right side of the heart?

a) blood can not go from one side of the heart to the other

b) through the body

c) through the lungs

d) through the body and the lungs

f - Structure

How many compartments are there in the heart?

a) 1

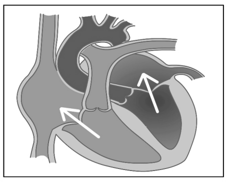
b) 2

c) 3

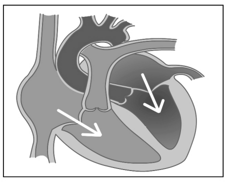
d) 4

g - Procedure

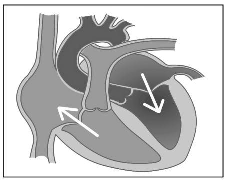
Within the heart blood flows from one compartment to the other. Which picture shows the direction of the blood flow correctly?



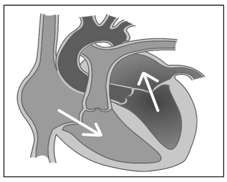
a)



b)



c)



d)

h - Timing

The exchange of oxygen in the body occurs……the exchange of oxygen in the lungs?

a) before

b) after

c) simultaneously with

d) none of the above answers is correct

Sample inference questions

- What causes the valves of the heart to close?
- Where does oxygen leave the blood and do waste products enter the blood?
- What causes the chambers of the heart to contract?
- Do the alveoli contain the same amount of oxygen at any moment in time? Explain.

Sample transfer questions

- Imagine a disease that harms the alveoli and reduces their functionality. What effect do you think this would have on the functioning of the heart and the blood circulation?
- Why is it necessary to have valves in the heart in order for the circulatory system to function properly? Explain your answer by taking into account the workings of the valves.
- The dividing wall that separates the left and right side of the heart may be damaged leading to a hole in the wall. Explain what consequences this would have on the functioning of the heart and the blood circulation.

Appendix C

Examples of content-free prompts

1. Could you explain how this works?
2. Explain what this means to you?
3. Could you be a little bit more specific?
4. Could you clarify what you just said?
5. Anything else that you can say about that?
6. Could you explain why it works like this?

Appendix D

Samples of real self-explanation statements

Paraphrases

Student 99: Ehm…The lungs first get bigger and then reduce in size.

Student 69: Blood is flowing through the arteries.

Student 96: Red dots are going into the lungs and blue dots are coming out of it.

Goal-driven explanations

Student 85: The electrical system gives some sort of a signal or shock so that the heart can pump the blood away.

Student 53: [If blood enters the heart, the valves open and then close,] so blood can't flow back to the upper chamber.

Elaborative explanations

Student 97: [The blood is first replenished with oxygen in the lungs and then] oxygen is carried to the muscle.

Student 57: One blood circulation is thus rich in oxygen and the other one contains waste products.

Student 69: The oxygen in the muscle lets you move your arm and things like that.

Monitoring statements

Student 64: I really don't know what it means as the alveoli change colors, they keep changing colors?

Student 95: [Yes, the electrical system is running over and over] but I can't figure out how it works.

Inference errors

Student 52: Maybe that electrical thing, ehhh, system takes up oxygen.

Student 64: The main reason the valves open is because they receive a signal from the electrical system.

Note: Content in brackets was represented in other categories of self-explanation statements generated for the animation by the participant.

Dankwoord

Dankwoord

Zoals de titel van dit proefschrift aangeeft, heeft het richten van aandacht een centrale rol gespeeld in mijn promotieonderzoek. In het dankwoord wil ik graag de aandacht richten op de mensen die direct of indirect een belangrijke bijdrage hebben geleverd aan de totstandkoming van dit proefschrift.

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Björn
Rotterdam, september 2009

Curriculum Vitae, Publications, and Presentations

Curriculum Vitae

Björn de Koning was born in Rotterdam, The Netherlands, on February 1st, 1981. He completed secondary education in 1999 at the Thorbecke Lyceum in Rotterdam. Hereafter, he started studying Psychology in Rotterdam at the Erasmus University Rotterdam. After having received a Bachelor's degree in educational and developmental psychology in 2004, he received a Master's degree in cognitive and biological psychology in 2005 (cum laude). Shortly after graduation, he started working as a Ph.D. student at the department of Psychology, Erasmus University Rotterdam, studying the effects of cueing on learning from animations. He was and is engaged in developing and teaching a number of bachelor psychology and/or practical courses, supervising several tutorial groups, and supervising theses of several bachelor and master students.

Publications

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