Proceedings of the Annual Meeting of the Cognitive Science Society

Title

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 34(34)

ISSN

1069-7977

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Publication Date

2012

When Students Don’t Benefit From Attention Guidance in Animations: The Role of Working Memory in Learning From Animations

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Abstract

The present study examined how students’ working memory capacity influences learning from animations with or without guidance. We tested three different conditions: visual guidance, instructional guidance, and no guidance. The results show that especially visual guidance was perceived as being helpful for making references between narration and display of an animation. However, students without guidance outperformed both groups of students with guidance on a domain-specific knowledge test. A significant interaction between type of guidance and working memory capacity revealed that visual guidance impeded learning in students with high working memory capacity, whereas instructional guidance impeded learning in students with low working memory capacity. Our results suggest that working memory capacity is an important learner variable that should be taken into account to understand intervention effects and to customize learning environments to learners’ needs.

Keywords: learning; working memory capacity; animation.

Introduction

Animations can make unseen movements, interrelationships, and interdependencies or “difficult-to-see” particles and components in a system visible and thus accessible to comprehension. Animation can be defined as “a pictorial display that changes its structure or other properties over time and which triggers the perception of a continuous change” (Schnotz & Lowe, 2008, p. 304). This definition also pertains to dynamic visualizations, for example, presentations of how a technical device works or how a complex object is assembled. After a long line of research, nowadays there is no doubt that well-designed animations are helpful tools for fostering learning and transfer in different domains (Höffler & Leutner, 2007; Linn, Chang, Chiu, Zhang, & McElhaney, 2011).

Disadvantages of animations in the context of learning are grounded in their transitory and simultaneous nature. First, the presentation of entities in an animation is time-limited and subject to transience. This can hamper processing of important pieces of information, especially when the learner has not paid immediate attention to the relevant animated parts. Second, the simultaneity that characterizes one of animations’ advantages for learning is potentially also a pitfall. When a series of events takes place at the same time, learners’ limited capacities may be overwhelmed. Hence, meaningful learning that requires learners to actively select and organize relevant information in order to integrate it into existing schemata in long-term memory can be impeded.

Motivated by possible disadvantages of animations, design factors have been proposed that aim at guiding learners’ visual attention (Ayres & Paas, 2007). We tested two promising ways of fostering attention guidance to relevant information in animations, namely instructional guidance by giving verbal instruction prior to the presentation of the animation and visual guidance by blurring out irrelevant information in the animation. In addition, we investigated the influence of working memory (WM) capacity on learning from animations with these two types of attention guidance.

Guidance in animations

Instruction

Providing instructions on how to select and integrate information that is presented in different modes can have a positive effect on learners’ attention allocation and, thus, on learning processes. Instructions can be given before rather than during the presentation of a certain learning environment in order to avoid interference with the display of the learning contents during the actual learning phase. On the other hand, processes of recalling and maintaining the instructions during learning may “bind” WM capacities.

In the context of multiple external representations, instructing learners on the functional relationships between representations can foster learning outcomes by guiding visual attention (Schwonke, Berthold, & Renkl, 2009). Gopher, Weil, and Siegel (1989) argue that mere prolonged exposure to a complex and dynamic task does not necessarily improve a learner’s performance. Instead, a complex task should be decomposed into subcomponents, and the focus of attention should be changed according to these predefined subcomponents. Computer game players who received instructions to focus on single sub-tasks—for example, first ship control and then mine handling—outperformed players without any instructions to change their focus (Gopher et al., 1989). When following these instructions, “by a systematic manipulation of emphasis on different task subelements, subjects were led to explore a wider range of attention strategies and improved their ability to cope with the high load of tasks" (Gopher, Weil, & Bareket, 1994, p. 389). Moreover, trainee pilots who first adopted strategies in attention allocation according to the emphasis change method in a computer game were better at actual piloting of an airplane than trainees who did not (Gopher et al., 1994). The emphasis change method works by way of external instructions prior to the learning phase. It is based on change of focus on components of a complex task and feedback (Gopher et al., 1989). However, it remains open whether such a method fosters only sensomotoric skills or also (meaningful) learning from animations.

Cueing

Cueing and signaling to highlight key information offer a more apparent and invasive way of attention guidance (Ayres & Paas, 2007). In general, cueing "refers to the addition of design elements that direct the learner's attention to important aspects of the learning material" (Plass, Homer, & Hayward, 2009, p. 39). Learners are not required to remember prior instructions. Cueing can be achieved by adding attention-directing objects such as arrows, circles, or colors to make relevant parts more noticeable. Another possibility is to reduce the luminance or the clarity of irrelevant parts in the visual display so that the important parts attract attention ("spotlight display"; Jarodzka et al., 2010). This technique makes animations less complex by directing learners' attention to relevant information, thereby reducing the search space and freeing capacities for meaningful learning (De Koning, Tabbers, Rikers, & Paas, 2010; Mautone & Mayer, 2001). Whereas arrows and colors run the risk of delivering too much new information, a change of luminance or acuity creates a spotlight and may be perceived as less distractive. The latter methods minimalize the visual display to the most important parts and events while preserving a holistic view. The advantages of cueing should fit especially the needs of learners with low WM capacity and those who are easily distracted by simultaneity.

In a study on learning a perceptual task (i.e., diagnosing seizures in infants), cueing was used to guide the learners' visual attention in a tutorial video. A spotlight display was superior to a circle display that was supposed to direct attention and to a control condition without visual guidance (Jarodzka et al., 2010). In line with these results, De Koning, Tabbers, Rikers, and Paas (2007) reported encouraging findings on the superiority of cued animations over non-cued versions in terms of comprehension and transfer performance. Unfortunately, these results could not be replicated. Cueing in an animation on the cardiovascular system did not lead to better learning outcomes than non-cueing, although eye tracking data revealed that learners' visual attention was guided more frequently to cued than non-cued contents (De Koning et al., 2010). In sum, it is unclear why learners do not always benefit from cueing, even when their attention was successfully directed to the relevant regions in the animations. Considering learner variables such as WM capacity may help in providing adequate answers to this open question.

Working Memory in Multimedia Learning

Learning and comprehension are dependent on learners' ability to allocate and regulate attention. Before information can be stored in long-term memory it has to be processed in WM (Baddeley, 2003). Given the limited capacity of WM, only a small amount of the perceived information can be actively processed in order to acquire knowledge in the form of schemas. In their review, Schüler, Scheiter, and van Genuchten (2011) showed that WM capacity is a stable construct that affects the processing of static multimedia learning material such as texts and graphics. Because of its constraints, capacity likely plays a prominent role in learning from animations which can put high demands on learners.

Animations are often complemented by narrations. Consequently, in addition to information presented in visual mode (i.e. display) learners have to integrate information presented in auditory mode (i.e., narration). This leads to simultaneous demands on different components of WM. Auditory information is processed in WM's phonological loop, while visual information from the animated visual display is processed in WM's visuo-spatial sketchpad. Both types of information have to be temporarily stored and integrated in the episodic buffer (Baddeley, 2003).

WM measures reflect a domain-free ability to hold and process several information chunks "actively" while ignoring irrelevant information through the control of attention. This ability varies between individuals and influences the task performance. Hence, higher WM capacity facilitates not only processing of multiple information but also suppression of distracting information. Individuals with high WM capacity outperformed individuals with low WM capacity on visual selective attention tasks thanks to their flexibility in allocating their attention to visual stimuli (Bleckley, Durso, Crutchfield, Engle, & Khanna, 2003). The same results apply to the auditory channel. In a replication of the cocktail party phenomenon, individuals with low WM capacities detected their name in an irrelevant message more often than individuals with high WM capacities did, indicating that low WM individuals are more susceptible to distraction; at the same time, high WM individuals outperformed low WM individuals on a shadowing task (Conway, Cowan, & Bunting, 2001).

The results demonstrate that WM capacity is of vital significance in the process of attention allocation to visual and auditory information. Thus, WM capacity should have an influence on learning from animations. Furthermore, it is reasonable to assume that learners with different capacities may require different types of attention guidance for successful learning. By implication, learners with different levels of WM span may react differently to the same instructional design, such as verbal instruction or visual guidance.

Hypotheses

In our approach, we tested the effects of two types of guidance in an animation depicting the processes within a technical device (i.e., parabolic trough power plant system). We tested three conditions: a visual guidance group, who watched an animation with a clear spotlight on the relevant information while the visual clarity of irrelevant parts was reduced; an instructional guidance group, who received an instruction prior to the animation to make references between the narration and the visual display; and a no-guidance group, who did not receive any guidance on how to process the animation. We tested the following hypotheses:

1. As part of a manipulation check, we expected that subjectively perceived difficulty to make references between narration and visual display would be higher in the no-guidance group than in the groups with guidance.
2. With regard to the learning outcome, we expected the guidance groups to outperform the no-guidance group on a domain-specific posttest.
3. Besides a general effect ("main effect") of WM capacity on the learning outcomes, we assumed an interaction between guidance and WM capacity. Participants with low WM capacity should benefit more from guidance than would participants with high WM capacity.

Method

Participants

The participants were *N* = 81 (62 female) students from the University of Freiburg (age *M* = 22.14, *SD* = 3.18). Participants were randomly assigned to one of three conditions: visual guidance, instructional guidance, or no guidance. Each condition comprised of 27 participants.

Materials

Prior knowledge test A pretest on prior knowledge of solar energy and the parabolic trough power plant system consisted of 30 items. Knowledge about technical devices entails being able to describe their structures, processes, and functions (Kalyuga & Hanham, 2011): Structures are the components an object consists of and their relationships; processes describe what happens in the system and how the device operates; functions characterize the purpose of the device and its sub-components and "provide" the answer to the question of what it is designed for. The prior knowledge test thus required participants to answer questions on solar energy in general but also on the structures, processes, and functions of the system (Cronbach's α = .79).

Learning performance In our animation structures, processes, and functions were specified visually and verbally by the visual presentation and narration. Hence, the posttest also comprised questions on the structures, processes and functions of the parabolic trough power plant. The learning outcome was assessed with 40 items. The overall reliability of the posttest was good (Cronbach's α = .90).

Test of WM capacity: Letter-Number Sequencing test (LNS) WM span was assessed by the Letter-Number Sequencing test measuring especially the WM and attention span (adapted from the German version of the Wechsler Adult Intelligence Scale, WAIS-III; von Aster, Neubauer, & Horn, 2009). Participants listened to a sequence of letters and numbers (e.g., T-9-A-3) and reproduced them afterwards, but were asked to place the numbers in numerical order and the letters in alphabetical order, (e.g., 3-9-A-T). The level of complexity was defined by the number of elements, namely letters and numbers. The test started with two elements, and the level of complexity gradually increased by adding one element at a time up to a final sequence of eight elements. For each correctly announced sequence participants received one point. All points were summed up to a total score (between 0 and 21 points).

Animation The animation was colored and lasted about 5 minutes. It depicted how a parabolic trough power plant and its three cycles (i.e., oil cycle, water-steam cycle, and salt cycle) work. Each cycle is characterized by unique structures and serves a specific role in the conversion of solar energy to electric power. The solar radiation as well as the direction and flow of the different fluids in the system were animated.

Corresponding to our three conditions, we developed three versions of the animation. The visual guidance version included cueing by blurring out the cycles of the system that were not in the focus of the narration. In this way, a holistic view of the animation was preserved, while the relevant parts were made more salient by "spotlights." The purpose of cueing was to visually guide participants' attention through the animation and to assist them in making references between narration and the animated visual display. In the instructional guidance version, participants had to read an instruction prior to the animation on how to make references between the narration and the visual display. They were informed that several things would happen simultaneously and that it was thus crucial to follow the narration and map it to the animation. A third version involved no guidance at all, neither visual nor instructional.

Procedure

Participants were tested in individual sessions approximately 60 minutes in length. After being explained the procedure, participants were asked to complete a short questionnaire on demographic data. They were then seated in front of a 22" computer monitor screen that was set at an operating distance of 60 to 80 cm. Next, prior knowledge was assessed and participants were asked to give subjective evaluations of their knowledge about the system (ten-point Likert scale from 1 = no knowledge to 10 = very good knowledge). The assessment of WM capacity followed (Letter-Number Sequencing), after which participants watched the animation. They were then asked to rate their knowledge about the system once again (after watching the animation), and asked how difficult it was for them to map between the narration and the animated visual learning content, again on a ten-point Likert scale. Finally, learning performance was assessed by a domain-specific posttest.

Results

First, we conducted a one-way ANOVA on the pretest. The conditions did not differ with respect to prior knowledge, $F(2,78) = 0.00$, $p = .998$, $\eta^2 = .00$. Before and after the animation, participants had to rate their knowledge about parabolic trough power plants. Participants in each condition showed a significant increase in their subjectively perceived knowledge about the system after having seen the animation (no guidance: $M_{before} = 1.30$, $SD_{before} = 0.87$; $M_{after} = 6.12$, $SD_{after} = 2.41$; $t(25) = 9.81$, $p < .001$, $\eta^2 = .79$; instructional guidance: $M_{before} = 1.26$, $SD_{before} = 0.71$; $M_{after} = 5.35$, $SD_{after} = 2.45$; $t(24) = 9.05$, $p < .001$, $\eta^2 = .77$; visual guidance: $M_{before} = 1.44$, $SD_{before} = 1.31$; $M_{after} = 5.00$, $SD_{after} = 2.74$; $t(25) = 6.50$, $p < .001$, $\eta^2 = .62$). There were no differences between groups with respect to their perceived knowledge after watching the animation, $F(2,74) = 1.73$, $p = .184$, $\eta^2 = .05$.

As part of our manipulation check, participants were asked to rate how difficult it was to map between the visual display and the narration during the learning phase. Because the assumption of homogeneity of variance was violated, we conducted a Kruskal-Wallis test. The type of guidance (experimental condition) significantly affected the perceived difficulties in making references between visual display and narration, $H(2)=7.57$, $p = .021$. Mann-Whitney tests were used to follow up this finding (Figure 1). There was no difference between the no-guidance group ($M = 5.19$, $SD = 2.47$) and instructional guidance group ($M = 4.22$, $SD = 1.93$; $U = 282$, $p = .149$, $r = -.20$), but participants in the no-guidance group reported significantly more difficulties in making references than did participants in the visual guidance group ($M = 3.48$, $SD = 1.63$; $U = 217$, $p = .009$, $r = -.35$).

Nor were there any differences in WM capacity (LNS) between the conditions, $F(2,78) = 1.42$, $p = .248$, $\eta^2 = .035$. Overall, WM capacity was positively correlated with the learning outcomes, $r = .32$, $p = .004$. To test our next two hypotheses, we performed a general linear model in which we predicted learning outcomes by condition, WM capacity (as continuous variable), and the respective interaction term. Condition had a significant effect on learning outcomes, $F(2,78) = 5.78$, $p = .005$, $\eta^2 = .133$. Pairwise comparisons revealed a significant difference between the no-guidance group and the instructional group, $p = .039$, as well as between the no-guidance and the visual guidance group, $p = .043$. The no-guidance group (adjusted $M = 26.20$, 95% CI [23.63, 28.78]) outperformed both the instructional guidance group (adjusted $M = 21.54$, 95% CI [18.95, 24.12]) and the visual guidance group (adjusted $M = 21.48$, 95% CI [18.77, 24.20]).

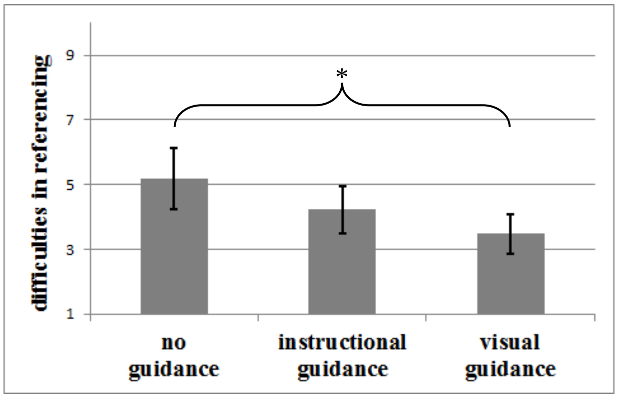

Figure 1: Perceived difficulties in referencing between visual display and narration (1 = none, 10 = many; 95% CI).

The effect of WM capacity on learning outcomes failed to reach statistical significance, $F(2,78) = 3.73$, $p = .057$, $\eta^2 = .05$. However, there was a significant interaction effect between WM capacity and type of guidance (experimental condition), $F(2,78) = 5.24$, $p = .007$, $\eta^2 = .12$. Students with low WM capacity were hindered by instructional guidance and students with high WM were hindered by visual guidance (Figure 2). Overall, no guidance was a good fit for learners with low as well as high WM span.

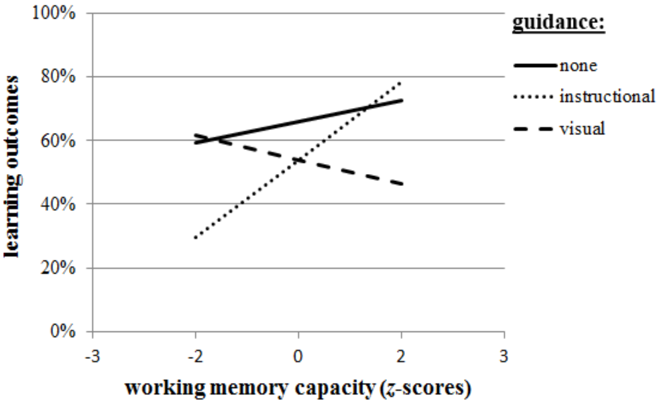

Figure 2: Interaction between working memory capacity (z-scores) and learning outcomes (%).

Discussion

The present study tested whether learners benefited from guidance in an animation on how a technical device works, and whether different types of guidance led to different learning outcomes. Furthermore, it investigated the interaction between learners' WM capacity and type of guidance. Learners in all conditions indicated a significant increase in their knowledge after watching the animation. In accordance with our first hypothesis, the no-guidance group reported the highest level of difficulties with making references between the visual display and the narration, followed by the instructional group and the visual group, who reported the fewest difficulties. Nevertheless, because only the difference between the no-guidance and visual guidance group was statistically significant, we consider our hypothesis only partially confirmed. Contrary to our expectations expressed in the second hypothesis, the no-guidance group outperformed both guidance groups on learning outcomes. Our third hypothesis was partially confirmed, given that WM capacity did affect learning from animations. In our experimental conditions, visual guidance had a detrimental effect on learners with high WM capacity, whereas instructional guidance had a detrimental effect on learners with low WM capacity. In general, the no-guidance group performed best, despite more perceived difficulties in making references. It follows that low WM learners benefited from no and visual guidance while high WM learners benefited from no and instructional guidance.

Contradicting conclusions drawn by Ayres and Paas (2007) that animations are more effective when key information is cued or signaled, our findings suggest that cueing does not necessarily have a positive effect on learning outcomes although it can reduce the level of perceived difficulties. Cueing as well as instruction aim at reducing cognitive load by directing learners to the relevant information in the learning content. Making references between different sources of information (auditory and visual) can be assumed to be an indicator of cognitive load. In this respect, visual guidance accomplished its purpose by synchronizing highlights on visual information with narration and hereby facilitating mapping. However, we assume that this might have led learners to invest less effort in active learning, after perceiving the content as (too) easy to comprehend. The framework of desirable difficulties offers an explanation as to why visual attention guidance does not always lead to better learning outcomes in the field of dynamic visualizations (De Koning et al., 2010): learners may be “lulled into a false sense of understanding” that makes them overestimate their understanding of the learning content (Linn et al., 2011, p. 239). Hence, an animation that is designed to make comprehension and processing subjectively too easy can mislead learners about the necessary effort. One might deduce from this that some degree of perceived difficulty can challenge learners and make them invest more effort in active learning processes. When learners perceive the stimulus as being more demanding, they may try to compensate for that by expending more effort in understanding the material (Salomon, 1984). Based on these findings, we propose that in order to promote active integration of learning materials, learners need to be given some challenges. More research is needed to find the balance between promoting effort and overload.

Another explanation for the poor performance of both guidance groups may be unfamiliarity with the chosen types of guidance. Blurring out the irrelevant parts can irritate learners. Visual guidance is an invasive form of alteration to the original display. It restricts learners’ natural exploration behavior to the highlighted parts of the learning environment; spotlights expose only the parts that are important for the immediate moment. As a consequence, a deeper holistic integration of past and present information may be disrupted. Instructional guidance, on the other hand, is a less invasive type of support, at least with respect to the visual display. However, it requires learners to keep the instruction in mind while processing the animation. In light of limited WM capacities, learning processes and recall of instruction may conflict; especially learners with low WM capacity may suffer from this type of guidance. High WM learners, by contrast, may be able to follow the strategy they were instructed to apply while simultaneously blocking irrelevant and distracting information through the course of learning. Furthermore, guidance, whether invasive or not, can interfere with already established strategies and, thus, with self-regulatory processes. In contrast to the method of emphasis change (Gopher et al., 1989), we did not offer any feedback to our participants in the instructional guidance condition, neither on their performance nor on their attention allocation. As a suggestion for further research we propose a real-time feedback on learners’ eye movements.

Narration per se influences a learner’s attention. It can evoke expectations and provide knowledge directly prior to the processing of visual information. Consequently, prior expectations and knowledge can affect attention allocation to a visual display and influence the integration of new information (Kriz & Hegarty, 2007). Narration can therefore function as a top-down guidance of visual attention (Kriz & Hegarty, 2007; Lowe & Boucheix, 2008). Students in the no-guidance condition were guided by the narration but still had enough room to explore the whole display and thus integrate diverse information. In sum, the no-guidance condition seems to be a perfect fit for learners who can self-regulate their needs according to their resources, for example, their WM capacity and prior knowledge. At this point it should be stressed that our participants were students in a highly selective psychology program who already had thirteen successful years of school education and thus may be considered highly experienced in learning from multiple external representations and dynamic visualizations.

Based on our findings, we suggest that future multimedia research should place more emphasis on learner variables such as WM capacity to shed light on intervention effects of instructional designs. From our point of view, WM capacity could play a severe role in learning processes that could be comparable to the significance of prior knowledge in this context (Kalyuga, Ayres, Chandler, & Sweller, 2003).

Acknowledgments

We thank our technical consultants and supporters: Adrian Skuballa for programming computer-standardized tests, Michael Kutz for bringing our storyboard to life, and Clara Pieck for giving our animation her professional voice. Furthermore, we thank our student assistants: Nicole

Dillner, Caroline Fortunski, and Sabina Panetta. This research was supported by the ScienceCampus Tübingen “Informational Environments” (Adaptable and Adaptive Multimedia Systems).

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