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Enhancing Learning from Dynamic and Static Visualizations by Means of Cueing

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The current study investigated whether learning from dynamic and two presentation formats for static visualizations can be enhanced by means of cueing. One hundred and fifty university students were randomly assigned to six conditions, resulting from a 2x3-design, with cueing (with/without) and type of visualization (dynamic, static-sequential, static-simultaneous) as independent variables. For transfer tasks, learners receiving dynamic visualizations outperformed learners receiving static visualizations. A main effect in favour of cued visualizations could be observed only for pictorial tasks, but not for transfer tasks. There was no interaction between type of visualization and cueing for any learning outcome measure. Taken together, the study suggests that dynamic visualizations may be beneficial whenever understanding concerning the dynamic features of a domain is crucial to learning. Cueing on the other hand may not necessarily lead to a deeper understanding, but supports to achieve a better comprehension of the depicted visualizations.

INTRODUCTION

In Natural Sciences education, pupils are often required to understand complex interrelations that change over time as well as to integrate methods and knowledge from various subject matters like biology, chemistry, or physics. However, the content in these subjects seems to be challenging, as students often fail to understand the movement, complexity, and interrelation of changes in Natural Sciences phenomena. One promising way to support learners' understanding of these phenomena may lie in the use of visualization in general, and dynamic visualizations (e.g., animations or videos) in particular. However, there is still a lack of research on how to design visualizations, so that they are best suited to achieve certain learning objectives. Hence, in the current study, we investigated different design features of visualizations that were aimed at fostering the understanding of complex interrelations that change over time.

THEORETICAL BACKGROUND

Learning from Dynamic and Static Visualization

When comparing the effects of static and dynamic visualizations in multimedia learning, the picture that arises remains somewhat unclear. In a review by Tversky, Bauer-Morrison and Bétrancourt (2002), most of the studies failed to show any advantages of dynamic compared to static visualizations. On the other hand, a meta-analysis by Höffler and Leutner (2007) revealed a medium-sized overall advantage of dynamic over static visualizations. Nevertheless, it also has to be noted that of the 76 comparisons considered in this meta-analysis, 55 still failed to show a superiority of dynamic over static visualizations, suggesting that there are specific boundary conditions under which the potential of dynamic visualizations may be more or less pronounced. Thus, instead of a global comparison of dynamic and static visualizations, a more promising way might be to specify when and why these types of visualizations might be best suited for learning (e.g., Bétrancourt, 2005; Schnotz & Lowe, 2008). In the following, this approach is chosen with regard to three aspects. First, the relative benefits of dynamic and static visualizations are discussed with respect to the learning domain that is in the focus of instruction. Advantages of dynamic visualizations should specifically become evident, when learners are required to understand the dynamics underlying a specific domain. Second, it is suggested that when analyzing the relative benefits of dynamic over static visualizations, one should also consider how static pictures are presented to learners. Third, it is argued that learning with dynamic and static visualizations can be enhanced if learners are guided in processing the visualizations and that under these conditions the advantages of dynamic visualizations will become even more pronounced. We will take up each of these points in turn.

Aptness of dynamic visualizations as a function of learning domains

Dynamic visualizations should be beneficial for domains that are supposed to be hard to mentally animate for learners, since dynamic visualizations show the motion and trajectory of objects in an explicit and continuous way (cf. Rieber & Kini, 1991). Moreover, because dynamic visualizations allow directly depicting dynamic features, such as velocity and acceleration, they should be especially suited for domains where a deeper understanding of these dynamic features is fundamental (cf. congruence principle, Tversky et al., 2002; see also Lowe, 2003).

These aforementioned benefits of dynamic visualizations apply in the domain of the current study, the physical principles underlying undulatory (i.e., wave-like) fish locomotion. For this domain, a deeper understanding of the trajectory, as well as its interrelations with the velocity and acceleration of the movement is crucial. Consequently, in a previous study using this instructional material, an advantage of dynamic visualization over sequentially presented static visualizations for transfer tasks (but not factual knowledge or pictorial recall tasks) was observed (Kühl, Scheiter, Gerjets, & Edelmann, 2011). These results occurred irrespective of the modality of the accompanying text, which served as second independent variable. They indicate that for this domain dynamic visualizations are specifically suited and more apt to get a deeper understanding of the content than a series of sequentially presented static visualizations. However, a series of sequentially presented static visualizations is not the only way of presenting static visualizations.

Learning with different formats of static visualizations

Concerning static visualizations, one can differentiate whether the static frames are presented sequentially (i.e., the pictures are shown one after the other) or simultaneously (i.e., all pictures are presented next to each other) – at least when more than one static frame is presented, which is an often articulated request to keep static visualizations as informationally equivalent as possible to a dynamic visualization condition (cf. Tversky et al., 2002). Up to now, only little research has been conducted regarding the comparison of dynamic visualizations to different types of static visualizations. These studies yielded inconclusive results: While in some studies a superiority of dynamic visualizations over static-sequential, but not over static-simultaneous visualizations was found (Boucheix & Schneider, 2009; Imhof, Scheiter, & Gerjets, 2011), in other studies a superiority of dynamic over static-simultaneous, but not over static-sequential visualizations was observed (Kim, Yoon, Whang, Tversky, & Morrison, 2007). Again, other studies found that dynamic visualizations were superior to both, static-sequential and static-simultaneous visualizations (Imhof, Scheiter, Edlemann, & Gerjets, in press; Wells, van Mondfrans, Postlethwait, & Butler, 1973).

Overall, the presentation mode of static visualizations appears to have an influence on their instructional effectiveness as compared to dynamic visualizations, whereby the low numbers of studies as well as their contradictory results make it yet difficult to predict how it will affect learning. To ensure that the superiority of dynamic over static visualizations, which was found in a previous study using similar instructional material (Kühl et al., 2011), is not only true for static-sequential, but also static-simultaneous visualizations, in the current study dynamic visualizations were compared to both types of static visualizations. Because of the properties for the domain at hand, it was expected that dynamic visualizations should be more apt for learners than any type of static visualizations for achieving a deeper understanding of the interrelations of changing elements underlying this domain.

Despite the fact that dynamic visualizations have been shown to be advantageous for this domain, they might be further improved, since a drawback of dynamic visualizations might still have been apparent in the material used by Kühl et al. (2011), namely a high degree of visual complexity (e.g., Lowe, 2003; Schnotz & Lowe, 2008). This high visual complexity might arise from the fact that the depicted information is changing continuously, hence making it difficult to accurately perceive relevant information (e.g., Lowe, 1999). Moreover, several elements may change at different locations within the dynamic visualizations at the same time, so that learners also have to attend to different areas of the visualizations where changes happen (cf. intra-representational split-attention; Schnotz & Lowe, 2008). Finally, less relevant aspects of the display may change, thereby guiding attention away from more relevant to less relevant aspects (e.g., Lowe, 1999). To reduce the visual complexity that might be constituted by these factors, and hence to foster learning, it has been suggested to use cueing (cf. de Koning, Tabbers, Rikers, & Paas, 2009).

Using cueing to guide learners' processing of visual information

In a broader sense, cueing can be regarded as emphasizing, as well as structuring, important aspects of instructional materials, without providing any additional content to the material, thereby guiding a learner's processing towards the emphasized aspects (e.g., Mautone & Mayer, 2001). In the context of learning from text and pictures, cues can have at least two functions: Cueing can guide a learner's processing *within* a representation or cueing can help to form coherence *between* representations, for instance, between text and visualizations (cf. de Koning et al., 2009). Note that when describing cueing within a representation, we will in the following exclusively refer to cueing within a visualization, but will neglect cueing within text, as the latter is not within the scope of the current study.

Within visualizations, a successful way to guide attention to relevant information lies in the usage of spotlights, as could be confirmed by recent eye-tracking studies. At this, a spotlight is also supposed to deemphasize less relevant distracting elements (e.g., de Koning, Tabbers, Rikers, & Paas, 2010). Another promising method with regard to cueing within a visualization might lie in a specific form of color-coding, where elements that belong together are depicted in the same color, thereby grouping these elements meaningfully (cf. de Koning et al., 2009). This might make it easier for a learner to organize the elements within a visualization into a coherent pictorial mental model (cf. Mayer & Moreno, 2003). Also, within a visualization it is not only possible to emphasize, but also to overemphasize certain aspects, such as characteristics of a movement, which in turn can improve understanding (e.g., Fischer & Schwan, 2010).

Moreover, cueing can be used to help learners to relate text to corresponding visualizations, thereby possibly supporting learners to mentally integrate these representations, which in turn is supposed to lead to a deeper understanding of the content (e.g., Mayer, 2009). A well-proven way to relate visualizations and spoken text can be realized by adding elements to the visualization only after they were mentioned in the text (e.g., Jamet, Gavota, & Quaireau, 2008; Jeung, Chandler, & Sweller, 1997; Ozcelik, Arslan-Ari, & Cagiltay, 2010). This approach additionally reduces the initial visual complexity of the visualizations, as the visualizations gradually build up.

As aforementioned, compared to static visualizations, particularly dynamic visualizations may possess a comparatively high degree of visual complexity. Cueing is assumed to counteract the factors which are supposed to constitute this high degree of visual complexity: For instance, a spotlight can deemphasize less relevant distracting elements, or gradually building up the visualization can reduce the problems arising from intra-representational split-attention. Furthermore, by means of cueing dynamic features of a movement can exclusively be overemphasized in dynamic visualizations, thereby supporting a learner to better understand these characteristics of the movement. For these reasons, the benefits of cueing might not only foster learning with visualizations in general, but might also be more pronounced for dynamic visualizations as compared to static visualizations.

To sum up, cueing possess a great potential in enhancing learning with visualizations. On the one hand, by means of cueing, a learner's processing can be guided, thereby possibly helping learners to select and mentally organize visual elements of a visualization into a coherent pictorial mental model, which might be reflected by better performance on pictorial tasks (e.g., Beck, 1987; Ozcelik et al., 2010). Moreover, by supporting learners to integrate text and visualizations, cueing might also lead to a deeper understanding of the content as might be measured by transfer tasks (e.g., Amadieu, Mariné, & Laimay, 2011; Ozcelik et al., 2010).

Hypotheses and Research Questions

Taken together, regarding the impact different types of visualization may have on learning, it was expected to replicate the finding of a previous study (Kühl et al., 2011). That is, performance on transfer tasks (but not on verbal factual knowledge or pictorial recall tasks) was expected to be better in dynamic visualization conditions than in both static visualization conditions, whereas no differences between the two presentation modes of static visualizations were assumed.

For cueing, we expected a main effect for pictorial recall tasks and transfer tasks, with learners in the cued conditions outperforming learners in the uncued conditions.

Furthermore, an interaction between type of visualization and cueing was hypothesized: Positive effects of cueing were assumed to be more accentuated in dynamic visualizations compared to both formats of static visualizations.

METHOD

Participants and Design

One hundred and fifty students (122 female and 28 male participants; $M = 22.47$ years, $SD = 3.07$) with various educational backgrounds from the University of Tuebingen, Germany, participated either for course credit or payment in the study. Students had to be native speakers of German; no students of physics were allowed to take part. Students were randomly assigned to one of six conditions, which resulted from a 2x3-design with cueing (with/without) and kind of visualization (dynamic, static-sequential, static-simultaneous) as independent variables. Twenty-five participants served in each condition.

Materials

The material consisted of a questionnaire on attitudes towards biology and physics, a prerequisite knowledge test, a spatial ability test, the instructional materials, and a knowledge test to measure learning outcomes.

Attitudes towards biology and physics. To control for individual differences with respect to attitudes towards biology and physics, an adapted and shortened version of an attitude scale by Russell and Hollander (1975) was used. It consisted of ten items which had to be rated on a 4-point Likert scale, ranging from 1 (totally agree) to 4 (totally disagree). Five items dealt with attitudes towards biology and were subsumed to a biology scale, while the other five items dealt with attitudes towards physics and were subsumed to a physics scale. Higher values indicated a more positive attitude towards the respective domain. The internal consistencies of the scales for this study can be considered as very good, with $\alpha = .87$ for the biology scale, and $\alpha = .89$ for the physics scale.

Prerequisite knowledge. The prerequisite knowledge test consisted of eight multiple-choice questions asking for the knowledge about the undulatory swim style as well as about basic concepts related to this topic (e.g., Newton's laws of motion; see the Appendix for a sample item). The eight multiple-choice questions consisted of four to six alternatives to choose from and for each question there were one to three correct answers. For each correct answer, learners were assigned one point and for each wrong answer one point was subtracted. Within a question, however, learners could at worst receive zero points. The maximum score was 12 points.

Spatial ability. To control for individual differences in spatial abilities, the mental rotation test (Vandenberg & Kuse, 1978) was used. It consists of 20 items, whereby each item presents a complex three-dimensional block figure and four choice figures. For each item, the participant has to choose which two of the four choice figures represent forms into which a target can be mentally rotated. There was a time limit of six minutes for solving this task. For each correct answer one point was given and for each wrong answer one point was subtracted, resulting in a maximum of 40 points and a minimum of -40 points.

Instructional material. The computer-based instructional material dealt with the physical principles underlying fish locomotion. This topic addresses the understanding of physical concepts in relation to movement characteristics such as trajectory, velocity, and acceleration. The material consisted of eight sections, which built upon each other. Particularly, these sections contained the themes 1) swimming styles, 2) pushing off the water, 3) body section and propelling element, 4) reversal point and baseline, 5) action and reaction, 6) magnitude of the reaction force, 7) breaking down the reaction force, as well as 8) interaction of forces of various propelling elements.

Each section consisted of visualizations and corresponding explanatory texts. The same spoken text (695 words) was used in all conditions. The instructional material was presented system-paced. Each section lasted between 45 to 77 seconds (in total 481 seconds), corresponding to the length of the spoken text for each section.

The visualizations were subject to experimental manipulation and differed with regard to type of visualization (dynamic, static-sequential, static-simultaneous) and the presence of cueing (with/without). Irrespective of these manipulations, all visualizations were placed in the middle of the screen.

In conditions with dynamic visualizations, there was always one animation showing an undulatory (i.e., wave-like) movement of a fish in a recursive fashion (see Figure 1). The animation depicted the same fish across the eight instructional sections, but focussed on different aspects of its movement by portraying the interplay of the trajectory and velocity of different body parts, the corresponding displacement of water, the sizes of the associated resulting forces and their direction, as well as the related swimming speed. These forces were represented as arrows and varied in length and spatial orientation depending on the force's strength and direction. For instance, in the section explaining the magnitude of the reaction force, the fish changed its frequency of the movement of the body parts to depict the relation of these changes and the associated changes in the sizes of the resulting forces (i.e., changing size of arrows) and the related swimming speed (i.e., changing speed of moving background).

In conditions with static-sequential visualizations, nine key frames were shown within each section that had been extracted from the corresponding animation. The key frames were displayed sequentially one after the other. The nine static key frames represented two loops of an undulatory movement, so that each learner had the chance to see a frame again in case he/she had missed the information the first time (see Figure 1). Each key frame of a section remained visible on the screen between five up to 14.5 seconds, depending on the time the spoken text referred to the particular position of the fish. As can be seen in Figure 1, key frame number one, number five and number nine showed the same position, as they represented the starting point and the end point of the undulatory fish movement. Moreover, always two key frames showed identical positions of the fish (i.e., key frames two and six, key frames three and seven, as well as key frames four and eight).

In conditions with static-simultaneous visualization, the first five key frames of the static-sequential visualizations were shown within each section[1]. They were presented next to each other, ordered from left to right. Each key frame of the simultaneous condition had only a fifth of the area of a key frame of the static-sequential visualization condition, so that they would fit on the monitor screen. Irrespective of the smaller size, everything relevant could be seen in the respective key frames.

The cueing procedure for visualizations consisted of different cueing methods: (a) showing elements only after they were mentioned in the text, (b) color-coding, (c) a spotlight, as well as (d) zoom-ins (and zoom-outs). These methods were implemented for all types of visualizations, with the aim of enhancing the visualizations by means of emphasizing important information and guiding a learner's processing. In the following, the different functions of these cues will be described in more detail: In order to guide processing and also to reduce the visual complexity in dynamic visualizations, particularly the problems of intra-representational split-attention, elements did not show up in the visualization until they were mentioned in the text (e.g., the arrows representing different forces). Moreover, important elements that belonged to the same concept were depicted in the same color (i.e., color-coding) to facilitate the organization of the visualizations' elements into larger functional units. For instance, all propelling forces were depicted in yellow, all reaction forces were shown in blue, and all lateral forces were colored violet. To counteract the problem that less relevant changing elements (e.g., the background of the visualization) may be distracting, a spotlight was added to guide a learner's attention to the most relevant location, occasionally accompanied by zoom-ins (and later zoom-outs) to highlight important aspects. Note that for each section in which a spotlight was realized, it appeared only after the visualization had been present for 2 seconds, so that participants could realize that the spotlight served as a manipulation within the visualization (cf. de Koning, 2010). Besides these manipulations, which were implemented for all types of visualizations, there were additional cueing methods that could be implemented in the dynamic visualizations condition only. On the one hand, when it seemed reasonable, the animation stopped in crucial states, for instance, to emphasize an important position of the fish's tail and its impact on the direction of the corresponding forces to highlight important aspects of this state. Furthermore, dynamic features of the movement of the tail, such as the changes in the velocity of the fin from its reversal point to its baseline, were occasionally overemphasized. This was done to make these changes more salient, with the goal to enhance learners' understanding of the depicted content.

It should be noted that arrows were an inherent property of the content (by conventions) and symbolized forces in all conditions, but were not used for visual cueing purposes (cf. Boucheix & Lowe, 2010).

Overall, the instructional material was similar to the material used in a previous study (Kühl et al., 2011); however, for the current study additionally the independent variable cueing as well as static-simultaneous conditions were implemented.

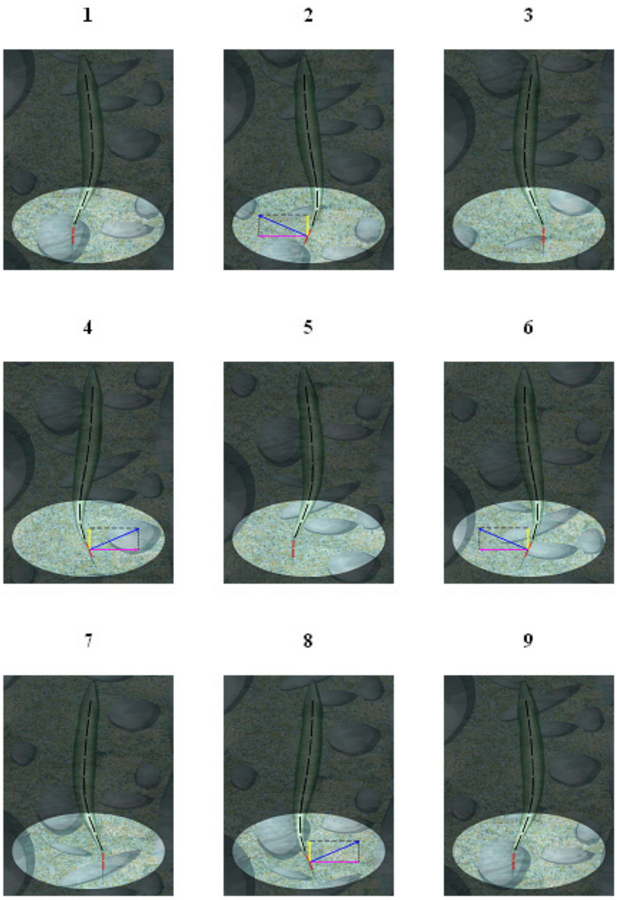

Figure 1. Sequence of Nine Static Key Frames of the Cued Static-Sequential Visualization Condition

Knowledge tests. Learning outcomes were measured by means of verbal factual knowledge tasks (eleven multiple-choice questions), five pictorial recall, and twelve transfer tasks (see Appendix for sample items of each test). The verbal factual knowledge tasks were posed in a verbal format and all correct answers were explicitly conveyed by the multimedia instruction. The pictorial recall tasks were posed in a pictorial format and asked for facts that were depicted by the visualizations. The transfer tasks were posed in written as well as in pictorial form. For solving the transfer tasks, learners had to apply their acquired knowledge to new situations.

The open questions of the pictorial tasks (4 of 5) as well as the transfer tasks (6 of 12) of 30 participants were scored by two independent raters. Cases of disagreement (3.26 %) for the open questions were resolved by consensus. As interrater-reliability was high (Cohen's kappa: .95), the remaining data were scored by one rater. Performance was transformed into percentage correct for ease of interpretation.

Procedure

Each participant was tested individually in a session lasting up to 120 minutes. First, the different control variables were assessed in the following order: attitudes towards biology and physics, the prerequisite knowledge test, and the mental rotation test (MRT). Thereafter, the system-paced learning phase began. Then students had to work on the different knowledge tests, namely the verbal factual knowledge test, followed by the pictorial recall test and finally the transfer test. The MRT and the open questions of the knowledge tests were paper-pencil based, while all other materials were presented via computer.

RESULTS

Means and standard deviations are reported in Table 1. Partial eta-squared (η^2_p) is reported as a measure of effect size.

Table 1

Means (and SD) as a Function of Type of Visualization and Cueing

Type of visualization	Dynamic		Static-sequential		Static-simultaneous	
Cueing	Yes (n=25)	No (n=25)	Yes (n=25)	No (n=25)	Yes (n=25)	No (n= 25)
Control variables						
Attitudes towards biology (5 – 20)	16.88 (2.91)	17.80 (2.63)	17.12 (3.27)	17.16 (3.46)	18.56 (2.76)	16.92 (3.73)
Attitudes towards physics (5 – 20)	10.72 (2.81)	12.68 (2.93)	12.80 (3.65)	13.20 (3.77)	12.36 (3.66)	13.24 (4.05)
Prior knowledge (% correct)	49.67 (15.12)	59.33 (19.29)	54.67 (19.85)	52.33 (18.24)	50.67 (19.97)	57.67 (21.51)
Spatial abilities (-40 – 40)	17.28 (10.26)	18.36 (8.22)	19.72 (10.13)	20.52 (9.77)	23.68 (9.43)	21.00 (9.70)

Table 1 Continued						
Learning outcomes (% correct)*						
Verbal factual knowledge	70.93 (3.47)	66.98 (3.39)	66.52 (3.39)	59.71 (3.40)	61.51 (3.43)	63.10 (3.40)
Pictorial recall	54.10 (4.33)	46.09 (4.23)	45.92 (4.22)	39.99 (4.23)	54.87 (4.27)	41.70 (4.23)
Transfer	51.90 (2.76)	48.74 (2.70)	46.30 (2.70)	45.35 (2.70)	45.85 (2.73)	43.27 (2.70)

*Note: Learning outcomes are adjusted by taking into account attitude towards physics and spatial abilities as covariates; values in parentheses refer to standard errors for these dependent measure

Control Variables

Two-factorial ANOVAs with cueing (with/without) and type of visualization (dynamic, static-sequential, static-simultaneous) were conducted to analyze if the learners in the six experimental conditions possessed similar prerequisite knowledge, attitudes towards biology as well as physics and spatial abilities. Concerning prerequisite knowledge, there were no differences for cueing ($F(1, 144) = 2.35$, p = .13, η^2_p =.02), type of visualization ($F < 1$, *ns*) and no interaction ($F(2, 144) = 1.36$, $p = .26$, η^2_p =.02). For students' attitudes towards biology, there also were no differences for cueing ($F < 1$, *ns*), or type of visualization ($F < 1$, *ns*), and no interaction ($F(2, 144) = 2.13$, $p = .12$, η^2_p =.03). For attitudes towards physics, there were no differences for type of visualization ($F(2, 144) = 1.99$, $p = .14$, η^2_p =.03) and no interaction ($F < 1$). However, there was a marginal significant difference for cueing ($F(1, 144) = 3.55$, $p = .06$, $\eta^2 p$ =.03), with students in the uncued conditions ($M = 13.04$, $SD = 3.58$) possessing slightly more positive attitudes towards physics than students in the cued conditions ($M = 11.96$, $SD = 3.47$). With regard to spatial abilities, there were no differences for cueing ($F < 1$, *ns*) and no interaction ($F < 1$, *ns*), but marginal significant differences occurred for type of visualization ($F(2, 144) = 2.77$, p = .07, η^2_p =.04), with learners in the static-simultaneous conditions possessing better spatial abilities ($M = 22.34$, $SD = 9.56$) than those in the dynamic visualization conditions ($M = 17.82$, $SD = 9.12$). Because the experimental conditions cannot be regarded as equal with respect to learners' attitudes towards physics as well as spatial abilities, these variables were used as covariates in all further analyses.

Learning Outcomes

Two-factorial ANCOVAs with cueing and type of visualization as independent variables and verbal factual knowledge, pictorial recall and transfer, respectively, as dependent variables were conducted, with learners' spatial abilities as well as attitudes towards physics as covariates.

With respect to type of visualization, the two-factorial ANCOVAs revealed no differences for either verbal factual knowledge ($F(2, 142) = 2.19$, $p = .12$, $\eta^2_p = .03$), or pictorial recall ($F(2, 142) = 1.52$, $p = .22$, $\eta^2_p = .02$). For transfer, there was a marginally significant effect for type of visualization ($F(2, 142) = 2.40$, $p = .09$, $\eta^2_p = .03$). Because we had hypothesized that dynamic visualizations would outperform both types of static visualizations for transfer tasks, planned contrasts between the dynamic visualization conditions and the two types of static visualization conditions were applied, using spatial ability and attitude towards physics as covariates. There was a significant effect ($F(1, 142) = 4.61$, $p = .03$, $\eta^2_p = .03$) indicating that, in line with our hypothesis, learners in the dynamic visualization conditions outperformed learners in both static visualization conditions for transfer tasks. There was no significant difference between the static-sequential and static-simultaneous conditions ($F < 1$, *ns*).

The two-factorial ANCOVAs revealed no effect of cueing on verbal factual knowledge ($F(1, 142) = 1.19$, $p = .28$, $\eta^2_p = .01$) and, in contrast to the hypotheses, also no effect of cueing on transfer ($F(1, 142) = 1.00$, $p = .31$, $\eta^2_p = .01$). However, cueing had an effect on pictorial recall ($F(1, 142) = 6.71$, $p = .01$, $\eta^2_p = .05$), with learners in the cued conditions ($M = 51.63$, $SE = 2.45$) outperforming learners in the uncued conditions as expected ($M = 42.59$, $SE = 2.45$).

With respect to the assumed interaction between cueing and type of visualization, the two factorial ANCOVAs revealed no interaction for any of the three learning outcome measures (all *F*s < 1, *ns*).

SUMMARY AND DISCUSSION

In the current study, enhancing learning with dynamic and two types of static visualizations by means of cueing was investigated with respect to different learning outcome measures.

First, it was expected that learning with dynamic as opposed to static visualizations would result in better learning outcomes, specifically for transfer tasks. The findings of this study support this assumption: Learners in the dynamic visualizations conditions outperformed learners in the static visualization conditions for transfer tasks, whereas no significant differences occurred for verbal factual knowledge and pictorial tasks, thereby confirming the results reported by the Kühl et al. (2011). Concerning the two formats of static visualizations, there were no differences for any of the three learning outcome measures, indicating that the presentation mode of static visualizations did not have an influence on their instructional effectiveness as compared to dynamic visualizations and hence played a subordinate role for this domain. The superiority of dynamic visualizations for transfer tasks indicates that the presentation of dynamic features like changes in velocity and their interrelations helped in constructing a deeper understanding of this domain. For future studies, it would be interesting to check the generalizability of this finding to other domains with similar dynamic features, for instance Kepler's second law, in which the understanding of the changes in velocity of the planetary motion around the sun is crucial.

Second, it was expected that cueing would enhance learning with dynamic and static visualizations, so that learners in the cued conditions would outperform learners in the uncued conditions, particularly for pictorial recall and transfer tasks. As expected, there was an effect of cueing for pictorial recall tasks, and not for verbal factual knowledge tasks. However, contrary to our expectations, cueing had no influence on transfer tasks. Hence, on the one hand, cueing helped learners to better recall the information depicted in the visualizations, but this did not lead to a deeper understanding of the content. One possible explanation may be that cueing mainly helps in mentally organizing and structuring visual elements, but contributes less to a more elaborated mental model from which inferences concerning interrelations of dynamic features can be drawn. This finding is partly in line with a recent review by de Koning et al. (2009), who could only find a positive effect of cueing in animations for approximately half of the reviewed studies and concluded that cueing does not necessarily lead to a deeper understanding of the content.

It should be noted though that cueing consisted of different cueing methods, such as synchronizing text and visualizations, a spotlight, zooming et cetera. All these manipulations were assumed to have a positive effect, and, hence were implemented to enhance the instructional material, which was a major goal of the current study. Consequently, it cannot be traced back which impact each manipulation had on the learner's processing of the materials. Also, it cannot be completely ruled out that different cueing manipulations interfered with each other - even if that appears to be unlikely, because prior studies indicated that the use of multiple cueing techniques is associated with best performance (e.g., Jamet et al., 2008). Nevertheless, the unique contribution of each cueing technique and their potential interactions need to be examined in future studies.

Third, contrary to our expectations, cueing was not more beneficial for learning with dynamic compared to static visualizations. On the one hand, we assumed that cueing should help to focus on the most relevant parts of the visualizations and to guide a learner's processing, which should be especially beneficial in dynamic visualizations, because dynamic visualizations are supposed to possess a comparatively high degree of visual complexity (cf. Lowe, 2003). Moreover, some cueing methods could uniquely be implemented in dynamic visualizations (e.g., overemphasizing changes in velocity), thereby, if anything, fostering the supposed interaction. However, our assumption was not confirmed. While cueing had no impact on transfer tasks for any type of visualization, it had an equally positive influence on pictorial tasks for all types of visualizations. Based on these results, several explanations might account for this finding. On the one hand, it may be argued that because several cueing techniques were applied, they may have had different influences on the respective types of visualizations. For instance, it may be possible that the manipulation of zooming in the visualizations was most helpful for the static-simultaneous visualizations, because the key frames shown in this condition were presented in the smallest size, whereas adding elements to the visualization only once they have been mentioned in the narration might have been most advantageous for learning with dynamic visualizations. Even though this explanation is notional, from a more principle-based point of view it might be worthwhile to investigate each manipulation separately. Another explanation for the absence of a moderating influence of cueing in learning with dynamic and static visualizations might be that the visual complexity of the dynamic visualizations for this specific instructional material might not have been the major problem. This may be the case, because, first, the content was segmented into multiple sections (cf. segmenting principle, Mayer, 2009), where the sections built up on each other and, correspondingly, the number of elements in the visualizations increased from section to section. Secondly, dynamic visualizations were shown repeatedly, so that learners in the uncued conditions had the chance to see relevant changes several times. These two factors might already have decreased the visual complexity of dynamic visualizations to a certain degree, and thus may have overshadowed additional potential cueing effects for dynamic visualizations, for which the strongest effect for cueing was expected. Hence, one may speculate that a moderating role of cueing in learning with dynamic and static visualizations might be observed, when the animations are for instance transient, so that a lack of or misdirected attention will be associated with a loss of information.

To sum up, the results of this study confirmed the hypothesis that dynamic visualizations in contrast to the two types of static visualizations were more apt for learners to get a deeper understanding of a domain like the one at hand. Cueing on the other hand, had no influence on tasks asking for a deeper understanding of the content, but it generally helped learners in mentally organizing and structuring visual elements into a coherent pictorial mental model. All in all, from an instructional point of view, these results suggest that it is worthwhile to produce dynamic visualizations for learning domains with properties like the one at hand, where the understanding of dynamic features like changes in velocity is crucial. Moreover, the results also indicate that adding cues to visualizations can at least enhance learners' recall of the information depicted in the visualizations.

References

Amadieu, F., Mariné, C., & Laimay, C. (2011). The attention-guiding effect and cognitive load in the comprehension of animations. *Computers in Human Behavior, 27*, 36-40.

Beck, C. R. (1987). Pictorial cueing strategies for encoding and retrieving information. *International Journal of Instructional Media, 14*, 332-346.

Bétrancourt, M. (2005). The animation and interactivity principles in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (pp. 287-296). New York, NY: Cambridge University Press.

Boucheix, J.-M., & Lowe, R. K. (2010). An eye tracking comparison of external pointing cues and internal continuous cues in learning with complex animations. *Learning and Instruction, 20*, 123-135.

Boucheix, J.-M., & Schneider, E. (2009). Static and animated presentations in learning dynamic mechanical systems. *Learning and Instruction, 19*, 112-127.

de Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2009). Towards a framework for attention cueing in instructional animations: Guidelines for research and design. *Educational Psychology Review, 21*, 113-140.

de Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2010). Attention guidance in learning from a complex animation: Seeing is understanding? *Learning and Instruction, 20*, 111-122.

Fischer, S., & Schwan, S. (2010). Comprehending animations. Effects of spatial cueing versus temporal scaling. *Learning and Instruction, 20*, 465-475.

Höffler, T. N., & Leutner, D. (2007). Instructional animation versus static pictures: A meta-analysis. *Learning and Instruction, 17*, 722-738.

Imhof, B., Scheiter, K., & Gerjets, P. (2011). Learning about locomotion patterns from visualizations: Effects of presentation format and realism. *Computers & Education, 57*, 1961-1970..

Imhof, B., Scheiter, K., Edelmann, J., & Gerjets, P. (in press). How temporal and spatial aspects of presenting visualizations affect learning about locomotion patterns. *Learning and Instruction*.

Jamet, E., Gavota, M., & Quaireau, C. (2008). Attention guiding in multimedia learning. *Learning and Instruction, 18*, 135-145.

Jeung, H., Chandler, P. & Sweller, J. (1997). The role of visual indicators on dual sensory mode instruction. *Educational Psychology, 17*, 329-343.

Kim, S., Yoon, M., Whang, S.-M., Tversky, B., & Morrison, J. B. (2007). The effect of animation on comprehension and interest. *Journal of Computer Assisted Learning, 23*, 260-270.

Kühl, T., Scheiter, K., Gerjets, P., & Edelmann, J. (2011). The influence of text modality on learning with static and dynamic visualizations. *Computers in Human Behavior, 27*, 29-35.

Lowe, R. K. (1999). Extracting information from an animation during complex visual learning. *European Journal of Psychology of Education, 14*, 225-244.

Lowe, R. K. (2003). Animation and learning: Selective processing of information in dynamic graphics. *Learning and Instruction, 13*, 247–262.

Mautone, P. D., & Mayer, R. E. (2001). Signaling as a cognitive guide in multimedia learning. *Journal of Educational Psychology, 93*, 377–389.

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge: Cambridge University Press.

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38*, 43–52.
Ozcelik, E., Arslan-Ari, I., & Cagiltay, K. (2010). Why does signaling enhance multimedia learning? Evidence from eye movements. *Computers in Human Behavior, 26*, 110-117.
Rieber, L. P., & Kini, A. S. (1991). Theoretical foundations of instructional applications of computer-generated animated visuals. *Journal of Computer-Based Instruction, 18*, 83-88 .
Russell, J. & Hollander, S. (1975). A biology attitude scale. *The American Biology Teacher, 37*, 270-273.
Schnotz, W., & Lowe, R. K. (2008). A unified view of learning from animated and static graphics. In R. K. Lowe & W. Schnotz (Eds.), *Learning with animation: Research and design implications* (pp. 304-356). New York: Cambridge University Press.
Tversky, B., Bauer-Morrison, J., & Bétrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies, 57*, 247-262.
Vandenberg, S. G., & Kuse, A. R. (1978). Mental Rotations, a group test of three-dimensional spatial visualization. *Perceptual Motor Skills, 47*, 599-604.
Wells, R. G., van Mondfrans, A. P., Postlethwait, S. N., & Butler, D. C. (1973). Effectiveness of three visual media and two study formats in teaching concepts involving time, space, and motion. *AV Communication Review, 21*, 233-241.

Appendix

Example of a question from the prerequisite knowledge test

According to Newton's second law of motion, a force F is calculated from

a) the product of mass and time

b) the product of mass and acceleration

c) the product of time and impulse

d) the product of impulse and acceleration

Example of a question from the verbal factual knowledge test

Which of the following is/are true?

a) The reaction force is perpendicular to the propelling element.

b) Lateral force and reaction force are perpendicular to each other.

c) Propelling force and lateral force are perpendicular to each other.

d) Reaction force and propelling force are perpendicular to each other.

Appendix Continued

Example of a question from the pictorial recall test

Three positions of an undulatory swimming fish are given below. The grey line symbolizes the baseline and the crosses symbolize the reversal points of the tail. However, the lower part of the fish is covered. Please draw the lower parts of the fish for the three given positions.

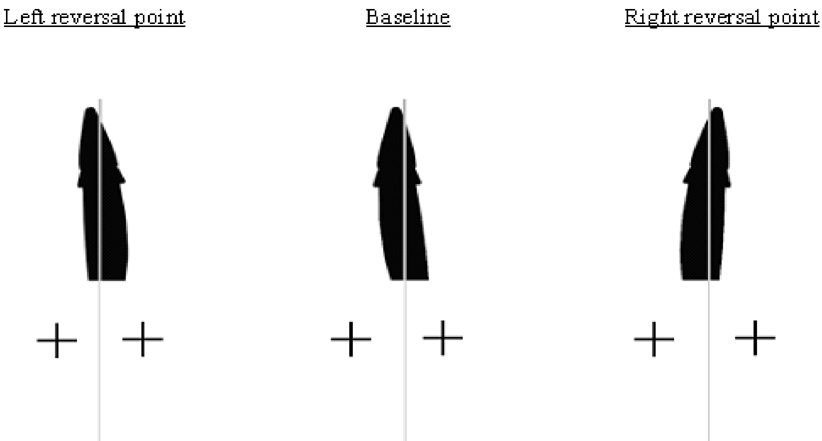

Figure A1. Example of a Pictorial Recall Task

Example of a question from the transfer test

Some undulating species of fish move their head back and forth in order to swim forwards. Why is this? Write down any feasible reasons you can think of!

Footnote

Footnote 1. Note that it was not necessary to show key frames number six to nine in the static-simultaneous visualizations condition as compared to the static-sequential visualizations conditions, since for the static-sequential visualization conditions these key frames were shown only to decrease the chances of missing information.

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