Realism in Dynamic, Static-Sequential, and Static-Simultaneous Visualizations during Knowledge Acquisition on Locomotion Patterns

Birgit Imhof (b.imhof@iwm-kmrc.de)
Knowledge Media Research Center, Konrad-Adenauer-Strasse 40, 72072 Tuebingen, Germany

Katharina Scheiter (k.scheiter@iwm-kmrc.de)
Knowledge Media Research Center, Konrad-Adenauer-Strasse 40, 72072 Tuebingen, Germany

Peter Gerjets (p.gerjets@iwm-kmrc.de)
Knowledge Media Research Center, Konrad-Adenauer-Strasse 40, 72072 Tuebingen, Germany

Abstract

In the current study the level of realism in visualizations and the role of diverse presentation formats of dynamic and different static visualizations in a complex, dynamic domain (locomotion pattern classification) were investigated. In a two-by-three design with the two independent factors realism (realistic, schematic) and presentation format (dynamic, static-sequential, static-simultaneous) one hundred-and-twenty university students were randomly assigned to six conditions. Learners had to learn how to classify fish according to their locomotion pattern. Learning outcomes were measured by two pictorial tests, assessing recognition and transfer performance. Data analyses showed an advantage of the dynamic conditions over the sequential conditions in both recognition and transfer performance. Simultaneous visualizations did not lead to different learning outcomes than either dynamic or sequential visualizations. Moreover, there was no main effect for realism or an interaction of realism with presentation format. Implications for the design of instructional materials are discussed.

Keywords: Animation; static pictures; realism; visualization.

Amount of realistic detail

In general, visualizations have the potential to support learners' understanding in complex and dynamic domains. However, visualizations are a broad field with various formats and functions (cf. Scheiter, Wiebe, & Holsanova, 2008). An important question is under what conditions the specific benefits of different visualization formats occur (e.g., Tversky, Bauer-Morrison, & Bétrancourt, 2002).

As identified by Höffler and Leutner (2007) in their meta-analysis, an important dimension of visualization design concerns the amount of realistic details depicted. According to Rieber (1994) "realism is somehow measured against the likeness of the object the picture is supposed to represent" (p. 148). This similarity is achieved by copying the real-world referent with respect to shape, details, texture, or color. The few empirical comparisons of realistic and schematic visualizations have yielded inconsistent results so far (cf. an overview Scheiter et al., in press).

Due to their high resemblance with depicted real objects realistic visualizations may facilitate their recognition (e.g., Goldstone & Son, 2005; Höffler & Leutner, 2007). However, they also entail more irrelevant details and therefore might direct learners' attention away from the important aspects (Dwyer, 1976). By schematizing visualizations, relevant aspects, which might be difficult to detect in reality, can be presented in an easier-to-perceive way. On the other hand, learners studying schematic visualizations might have difficulties when being confronted with real-world phenomena. Dwyer (e.g., 1976) did a lot of research on the question what amount of realistic detail depicted is useful in static visualizations. It could be shown that the relative efficiency of realistic and schematic visualizations depends on several factors. First of all, the learning goal has an influence, because what has to be learned may lead to different needs for information regarding details or more schematized aspects. Another important aspect is the presentation method, that is, the interactivity in the form of self-controlled versus system-paced learning environments.

Our assumption is that in a learning task about movement pattern classification only details necessary for movement recognition should play an important role. Additionally, the presentation format of the visualizations also might have an influence. In line with the latter assumption, the meta-analysis of Höffler and Leutner (2007) found dynamic visualizations particularly effective when they are realistic.

Presentation formats of visualizations

A second and probably the most common differentiation of visualizations is the one between dynamic and static ones. There are several meta-analyses concerning comparisons between animated and static displays, which led to equivocal results so far. Park and Hopkins (1993) found that dynamic visualizations were better than static ones in 15 out of 27 comparisons, whereas there were no differences between dynamic and static visualizations in the remaining 12 comparisons. Interestingly, in none of the studies static visualizations were superior to dynamic ones.

In the meta-analysis of Höffler and Leutner (2007) an overall advantage of instructional animations (i.e., dynamic visualizations) over static visualizations could be found.

Tversky and colleagues (2002) questioned in their review the findings that dynamic visualizations are in general superior to static ones and identified two aspects, which may explain the advantages of dynamic visualizations. First, in a couple of studies (see Tversky et al., 2002, for an overview) the dynamic visualizations entailed more information than the static ones. This additional information may have caused the better learning outcomes of dynamic conditions. Second, many of the dynamic visualizations are interactive. Following Mayer and Chandler (2001) a minimal amount of interactivity already leads to better learning outcomes. Hence, if the dynamic visualization is interactive and the static one is not, the interactivity and not the dynamic aspects may be the reason for better learning outcomes in the dynamic conditions.

The inconclusive result pattern indicates that there may be moderators that will have an impact on whether dynamic visualizations are superior to static ones or not (Tversky et al., 2002). Accordingly, in the last few years more and more studies have aimed at identifying crucial aspects – that may act as moderators – concerning the effectiveness of dynamic visualizations. Some beneficial conditions under which the potential of dynamic visualizations could be tapped have already been identified. For example, Tversky and colleagues (2002) postulate the congruence principle, whereby animations are effective in the case that the learning content can be directly depicted in the dynamic materials because it is dynamic itself. Thus, dynamic visualizations should be especially suited to convey knowledge about dynamic domains. Furthermore, the meta-analysis of Höffler and Leutner (2007) found dynamic visualizations superior to static ones especially when the dynamic visualizations involved procedural-motor knowledge. Additional supporting evidence for the superiority of dynamic visualizations has been found with hand manipulative tasks (i.e., human motor skills; Ayres et al., 2009; Wong et al., 2009). Although the superiority of dynamic visualizations regarding movement has been found exclusively for human movements so far, it can be argued that human motor skills are an example of what is called biological motion (Johansson, 1973). Hence, the latter findings may suggest that dynamic visualizations are better suited to convey biological motion in general.

Moreover, how effective a dynamic visualization is, also depends on the fact to what the dynamic visualization is compared with. There are several different presentation formats of static visualizations which may all serve as objects of comparison for dynamic visualizations.

The presentation of static pictures can vary with respect to different aspects. For example, the number and the size of pictures shown may be different; the duration of the presentation of single pictures may vary with the content; and of course the presentation format of static visualizations regarding their sequentiality can be different. Multiple static pictures may be presented either sequentially, that is, one after another at the same position on the screen so that earlier pictures are replaced by later ones, or simultaneously, that is, all together on one page.

The two presentation formats, namely sequential and simultaneous presentation of multiple static pictures, can be characterized by different benefits and drawbacks for learning. On the one hand, the temporal alignment of visual elements is easier in a sequential presentation due to almost identical spatial positions. However, a sequential presentation of multiple static visualizations is more similar to a dynamic presentation, because it is still transient (Hegarty, 2004, Lowe, 1999). On the other hand, in a simultaneous presentation the depicted information remains visible on the screen and therefore comparisons among discrete steps are enabled. Additionally, learners can regulate the pacing of the cognitive processing.

The question of how to present static pictures has not been considered in the aforementioned meta-analyses and reviews. Static visualizations have often been lumped together into a single category, whose effects were then compared to dynamic visualizations. Up to now, there are barely any studies concerning the sequentiality of static visualizations (sequential versus simultaneous) and the possible benefits these options offer. One exception is a study by Boucheix and Schneider (2009), who showed that in a mechanical domain, simultaneous static pictures improved performance compared to sequential ones and were as good for learning as dynamic visualizations. The results of this study are a first indication that sequential static visualizations are worse than simultaneous ones.

Research Questions

In the current study we first tested whether dynamic visualizations are superior over both (sequential and simultaneous) static formats and whether simultaneous representations show benefits over sequential ones in complex, dynamic domains. Second, we were interested in whether realistic or schematic visualizations are superior in complex dynamic domains concerning locomotion patterns classification and whether realism in visualizations moderates the effectiveness of different presentation formats (i.e., dynamic, sequential-static, and simultaneous-static).

Experiment

Method

Participants. One hundred-and-twenty university students (average age: 24.23 years, SD = 3.90; 91 female and 29 male) were randomly assigned to one of six conditions resulting from varying the two factors realism and presentation format (dynamic-realistic, dynamic-schematic, static-sequential-realistic, static-sequential-schematic, static-simultaneous-realistic, and static-simultaneous-schematic).

Learning domain and materials. Students were asked to learn how to classify fish according to their locomotion patterns. Biodiversity is a central concept in biology education. There are more than 20,000 species of fish known in the world today. Among these not only a rich variety of forms and colors, but also a rich variety of adaptations related to swimming behavior can be observed (Videler, 1993). For biologists it is necessary to acquire knowledge about fish locomotion, because of at least two reasons: First, knowledge about different fish locomotion forms is helpful to classify diverse fish families or species. Second, the various movement patterns are related to several important principles in biology (e.g., evolutionary adaptation) and principles in other sciences (e.g., physics).

The materials were designed to illustrate four different types of movement patterns (subcarangiform, balistiform, tetraodontiform, and labriform) deployed by different types of fish. As a first independent factor we manipulated the *realism* of the visualizations to investigate under which conditions certain visualization formats support the understanding of fish locomotion. We compared experimental conditions that contained realistic representations of movement patterns (real digital videos or sequences of stills, see Figure 1 left) to conditions that contained schematic representations (animations or sequences of frames, see Figure 1 right). The dynamic-realistic visualizations were real underwater videos of actual fish, where the movement pattern could be observed very well (e.g., relevant fins were visible, few occlusions etc.). The animations consisted in black-and-white line drawings of the fish moving, where irrelevant details were left out (e.g., texture, surroundings, variations in shape etc.). The animations were constructed based on the real videos to make them as comparable as possible regarding other aspects (e.g., perspective, size of the depicted fish).

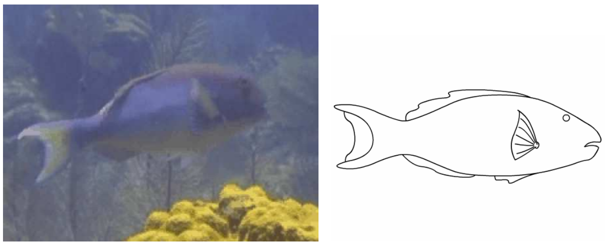

Figure 1: Example of realistic (left) and schematic (right) static visualizations of the labriform locomotion pattern

To investigate whether dynamic representations are more suitable than static sequential and static simultaneous representations to support students' understanding of fish locomotion classification and whether static simultaneous representations show also advantages over sequential ones in complex dynamic domains, we varied *presentation format* as a second independent factor. We compared experimental conditions that contained non-interactive dynamic representations of movement patterns to conditions that merely contained a series of static representations of one movement cycle of these movement patterns. As dynamic visualizations we used videos and animations. As static visualizations we used multiple stills and frames extracted from the dynamic visualizations. Nine static visualizations were extracted from the videos and from the animations for each locomotion pattern, thereby achieving the same quality of the pictures. The static visualizations were chosen by an expert and represented key states in the complete movement cycle for the respective locomotion pattern. Because fish movement cycles are very fast, almost every still and frame of the dynamic visualizations was used in the static versions. There were two different static conditions. The static visualizations were presented either sequentially one after another or simultaneously all together on one page.

The dynamic visualizations (approx. 4-10 s; 25 fps) were presented in loops for 72 seconds. The static sequential visualizations were presented successively twice for four seconds each in the same size as the dynamic visualizations (480 x 360 px). For the simultaneous static visualizations the same pictures were used as in the sequential conditions and were presented for 72 seconds all together on one screen. The pictures' size was half (240 x 180 px) of the size of the dynamic and the sequential static visualizations. Therefore, there was no need for the subject to scroll, because all nine pictures fitted to the screen at once.

In the learning phase the participants saw visualizations for each of the four to-be-learned locomotion patterns in a predefined order according to the classification scheme of Lindsey (1978). The presentation was system-controlled and accompanied by auditory text. The text explained the depicted locomotion pattern in terms of typical fish using this locomotion pattern, body parts or fins involved, kind of movements executed (undulation versus oscillation), parameters of the movements (e.g., visible wavelength on the moving parts, amplitude), and the maximum velocity. The important features of the locomotion patterns were depicted additionally in a table located above the visualizations during the learning phase in each condition.

In a former study, we tested the same materials with pictorial tests and also with a text-based factual knowledge questionnaire assessing declarative knowledge. In line with Bétrancourt and Tversky (2000) dynamic visualizations were superior only in the pictorial tests assessing more procedural-based knowledge concerned with the ability to identify the locomotion patterns of different fish. These tests are most suited to address the key learning objective in this domain and were hence used again in the current study. First, there was a movement pattern recognition test consisting of 24 pictorial multiple choice items. Visualizations from all six conditions were used in this test as stimuli that had to be recognized. Learners had to choose for each pictorial item the kind of locomotion pattern that was depicted. Possible answers were the four locomotion patterns and the additional answer "I don't know". Figure 2 shows a static recognition task for the balistiform locomotion pattern.

Second, a multiple choice transfer test consisting of 12 items that depicted "new" fish that had not been presented in the learning phase was administered. As for the recognition task, for these pictorial items of novel fish the subjects had to choose the depicted locomotion pattern (cf. Figure 2). The movement patterns were clearly identifiable in the transfer test videos, but the fish had different forms, shapes, and colors than those used in the learning phase. The transfer test was used to assess how good learners could transform their acquired knowledge on new fish performing familiar locomotion patterns. Because typical scenarios for this task are realistic ones with real fish (e.g., aquaria, snorkeling or diving trips), all 12 transfer items were tested in realistic format, four of them in static-sequential format, four in static-simultaneous format and four in dynamic format.

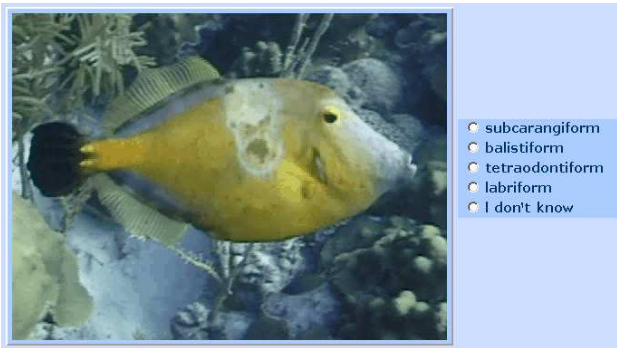

Figure 2: Screenshot of a realistic static-sequential recognition task of the balistiform locomotion pattern

Procedure. Participants were tested individually. They first got a short overview on the study in which they were informed about the procedure. Subsequently, they had to complete a personal questionnaire assessing demographic data. Then, they had to read a paper-pencil-based introduction (four pages). Thereafter, they started with the computer-based learning phase (approx. 10 min). Finally, learners worked immediately after the learning phase on the different tests (approx. 15 min). In total, an experimental session lasted approximately 55 minutes.

Results

We conducted two-way independent analyses of variance (realism x presentation format) for recognition and transfer performance (results are shown in Table 1). Because of space limitations, statistical values are only reported for significant results.

Analyzing the effects of realism on learning outcomes revealed no differences between the realistic and schematic conditions for both, recognition and transfer performance.

With regard to presentation format, the analysis revealed overall main effects for both, recognition, $F(2, 114) = 6.84$, $MSE = 491.18$, $p = .002$, $\eta^2_p = .11$ and transfer performance, $F(2, 114) = 7.27$, $MSE = 657.99$, $p = .001$, $\eta^2_p = .11$. Bonferroni-adjusted pairwise comparisons revealed that dynamic visualizations led to significantly better recognition ($M = 85.10$ %, $SD = 19.10$) and transfer performance ($M = 77.08$ %, $SD = 23.85$) than sequential visualizations (recognition: $M = 66.77$ %, $SD = 23.37$; transfer: $M = 55.21$ %, $SD = 25.65$; all $ps \leq .001$). The simultaneous conditions (recognition: $M = 75.83$ %, $SD = 23.08$; transfer: $M = 65.83$ %, $SD = 26.74$) did not differ in their performance from either the dynamic or the sequential conditions.

Table 1: Means (and standard deviations) in percent correct as a function of realism and presentation format.

	Recognition	Transfer
dynamic-realistic	86.88 (17.69)	77.50 (24.35)
dynamic-schematic	83.33 (20.72)	76.67 (23.97)
static-sequential-realistic	65.42 (27.01)	54.58 (28.67)
static-sequential-schematic	68.13 (19.70)	55.83 (22.96)
static-simultaneous-realistic	77.50 (22.35)	61.67 (28.66)
static-simultaneous-schematic	74.17 (24.24)	70.00 (24.69)

There were no interactions between the two independent variables realism and presentation format for the two dependent variables recognition and transfer.

Discussion

The objective of this study was to test the relative effectiveness of different visualization formats to foster knowledge acquisition in the complex dynamic domain of classifying biological locomotion patterns.

The results are in line with the hypothesis that dynamic visualizations are beneficial for conveying knowledge about dynamic movements. Furthermore, the results indicate that the sequentiality of the static presentation format has an influence on learning outcomes. The sequential presentation of static visualizations was worse in comparison to the dynamic presentation format. In contrast, the simultaneous presentation of static visualization did not differ from the dynamic presentation in a biological domain, thereby replicating the findings of Boucheix and Schneider (2009). This was the case although in the current study dynamic visualizations were compared to either sequentially presented or simultaneously presented visualizations in a completely different domain than the one used by Boucheix and Schneider (2009; mechanics) containing mainly procedural aspects. These findings lead to the question whether in former studies and meta-analyses information about the presentation format of the static conditions may have shed light on the inconsistent results concerning the superiority of dynamic visualizations. In future research and following meta-analyses the factor sequentiality of the static presentation of visualizations should be considered. Additionally, there is the need to further address questions concerning the effectiveness of different static presentation formats that include more aspects than only sequentiality, but also the number and the size of the pictures shown or the duration of the presentation of single pictures to mention only a few.

A sequential presentation of static visualizations is the presentation format that is most comparable with dynamic visualizations. Like in dynamic visualizations there are only few visual search and comparison processes possible. The comparison of various aspects and objects at different points in time is not possible. Hence, this presentation format is almost as transient as dynamic visualizations (Hegarty, 2004). The results show that this visualization format in comparison to dynamic visualizations has no benefit for the transmission of knowledge in complex dynamic domains. Simultaneous static visualizations, on the other hand, allow learners to compare important states of the objects. In our study we could show that simultaneously presented static visualizations are as good for learning as dynamic visualizations. This result suggests the possibility that learning about locomotion pattern classification depends not only on the continuity of the movements, but also on comparisons among different states of objects. Therefore, an open question is whether there are simultaneous presentation formats, which may even outperform dynamic presentations, because they facilitate comparisons among the important states of the objects in an even better way. In the present study the simultaneous static visualizations were depicted in a row, where comparisons mostly had to be made from left to right or vice versa. Another possible solution would be to depict the simultaneous static visualizations in columns, where comparisons have to be made from upper to lower positioned pictures or vice versa. Having in mind that the movement patterns of fish are all cyclic (i.e., reiterating), a beneficial solution would also be to present the simultaneous visualizations in a cycle, what avoids skipping back to the beginning of the row or column. These possible simultaneous presentation formats of visualizations are investigated in a follow-up study (currently being under experimentation) that investigates how different presentation formats affect learners' knowledge acquisition.

There were no overall differences in learning outcomes between realistic and schematic visualizations. Proponents of realistic visualizations have suggested that a visualization rich in detail should improve recognition because more cues are available that allow retrieving the resulting mental representation from memory (cf. Dwyer, 1976). These suggestions could not be confirmed in the present study. Interestingly, even for the transfer test that consisted of only realistic items there was no advantage of realistic visualizations in the learning phase in terms of a congruency effect. In other words, schematic visualizations were as good for transforming knowledge to new realistic visualizations as realistic ones.

If both realistic and schematic visualizations had specific advantages and drawbacks for learning, further research should focus on how to combine the advantages of both formats, while reducing their relative drawbacks. One possible solution is to present both, realistic and schematic visualizations, to learners. This approach can be best addressed against the background of research on learning with multiple representations, which allow providing instructional materials that are suited to accommodate learning in a variety of situations and for different learners (Ainsworth, 1999). Showing both realistic and schematic visualizations to learners may improve learning for a wider range of tasks compared to studying only one visualization format. However, for this approach to be effective, it needs to be guaranteed that both formats have individual strengths for accomplishing different tasks and that the learners will invest sufficient effort in processing both formats and in relating them to each other (Scheiter et al., in press).

Another possible solution is to combine different amounts of realism in a single visualization to support understanding in this domain. Realistic visualizations facilitate an assessment of the movement as a whole, which suffices for recognizing the global pattern. Therefore, it is possible that only the realistic details on the moving object (in our case) and not the realistic details of the background are helpful. The benefits of realistic objects might be cancelled out in the present study by the irrelevant details conveyed by the realistic backgrounds (e.g., coral reefs etc.). Maybe learning outcomes could be improved by showing the realistic details on the moving object only, in our case the fish, and reducing learners' cognitive load by fading out irrelevant details of the background. With the present materials consisting of real videos and simple black-and-white line drawing animations this aspect could not be addressed, although it should be controlled and investigated in further research. Distinguishing between realistic details of the relevant objects and the background would be possible with highly realistic animated models of the objects moving in front of a highly realistic background. When there is the possibility to fade out the realistic details separately either from the objects or from the background, the benefits and drawbacks could be systematically addressed. Such a design would not only enable us to implement a medium amount of realistic details depicted; rather, it would combine the two extreme points by mixing them in a single visualization by having a realistic fish on a schematized background and vice versa. This design is planned for a follow-up study investigating differential effects of realistic details referring to either relevant or irrelevant aspects of the stimulus.

Creating highly realistic animations of the to-be-learned contents rather than using digital real underwater videos as in the current study has another important advantage. Additional realistic details can be presented in a systematically controlled way. That means important aspects, such as the perspective and the duration of the presentation can be controlled. Especially the perspective from which position the learner looks at the objects, in our case fish, is important. For different locomotion patterns different perspectives would be useful. Wavelike movements are easier to perceive from above, whereas for paddlelike movements a perspective from the side or behind the fish (depending on which fins are used for propulsion) would be more preferable.

Additionally, the learning material could be interactive by letting the learners choose the perspective or other aspects of the learning materials, such as the presentation speed or duration. Future studies need to address whether learning with dynamic and static visualizations can be further enhanced by making them interactive (Bétrancourt, 2005). In the current experiment, no interactivity was included; thus, the dynamic visualizations could not be adapted by a learner to his/her processing speed. Nevertheless, dynamic visualizations proved to be superior to static visualizations.

Moreover, in future research the validity of the learning materials should be addressed outside of the laboratory. Therefore, field experiments with knowledge tests on actual fish during aquaria visits or snorkelling excursions should be investigated (cf. Pfeiffer et al., 2008; Pfeiffer et al., in press).

The results of the current study reflect what some researchers (e.g., Hegarty, 2004; Tversky et al., 2002) already supposed. It should not be asked which kind of visualization format is the most suitable, but when, under what conditions, and for whom the specific advantages of various visualization formats occur. This also implies to make more use of pictorial test stimuli in future research as these stimuli seem to provide a more detailed account concerning the relative effectiveness of different visualization formats (cf. Bétrancourt & Tversky, 2000).

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