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The realism paradox: Realism can act as a form of signaling despite being associated with cognitive load

Alexander Skulmowski | **Günter Daniel Rey**

Psychology of Learning with Digital Media, Chemnitz University of Technology, Chemnitz, Germany

Correspondence
Alexander Skulmowski, Psychology of Learning with Digital Media, Chemnitz University of Technology, Straße der Nationen, 12 09111 Chemnitz, Germany.
Email: alexander.skulmowski@phil.tu-chemnitz.de

Abstract

Realistic graphics have been found to result in a worse learning performance than schematic visualizations. These negative results of realism are usually explained by assuming that realistic visualizations induce more cognitive load. Therefore, realism has been linked to the facet of extraneous cognitive load in the model of cognitive load theory. However, recent results indicate that realism may be used to good advantage when it is utilized only in selected parts of visualizations. We tested the hypothesis that realism can be used as a form of signaling. In an experimental study (N = 50), we presented each participant with one realistic and one schematic anatomical visualization. As predicted, retention performance was highest for the realistic components. Furthermore, we found that extraneous load ratings were overall higher when a particularly detailed visualization was shown to participants (although no main effect of realism was found). Our results can be explained in terms of the disfluency effect, which holds that more visually demanding learning materials can in some cases enhance learning. An important implication of the study is that educators may use the degree of realism to focus learners' attention.

KEYWORDS

cognitive load, disfluency, e-learning, human cognition, human-computer interaction, instructional design, learning, realism, signaling, visualization

1 | INTRODUCTION

Realistic computer-generated graphics are ubiquitous, as current technology provides designers the possibility to create highly detailed visualizations. Visual realism is typically defined as the degree of fidelity of graphical representation to a real object (Rieber, 1994, p. 148). Thus, designers have the possibility to depict any object in a wide range of realism degrees, from schematic and stylized renderings to faithful realistic visualizations (Höffler, 2010). However, the effects of realistic visualizations on learning performance are not clear-cut (Lin, Holmqvist, Miyoshi, & Ashida, 2017; Scheiter, Gerjets, Huk, Imhof, & Kammerer, 2009). Although there are several studies comparing realistic graphics to less realistic, schematic, or other kinds of abstract visualizations in learning tasks (Scheiter et al., 2009), few general guidelines for the use of realism in instruction exist (Lin et al., 2017). To shed more light on the complex relationship between realism and learning, the present study investigates a more specific function of realism, namely whether realism trumps schematic visualizations in terms of grabbing learners' attention.

2 | EFFECTS OF REALISM ON LEARNING

As alluded to above, there have been several contradicting findings concerning the effects of realistic visualizations on learning. For instance, some studies found that realistic graphics do not improve learning (or even hamper with learning) compared with less realistic versions (Dwyer Jr, 1969; Scheiter et al., 2009). Yet, some authors describe the positive effects of realism (Huk, Steinke, & Floto, 2010) or at least positive outcomes for specific types of learners (Brucker, Scheiter, & Gerjets, 2014; Huk, 2006). Huk et al. (2010) found the benefits of a 3D animation compared to a two-dimensional version in one of their two studies. Building upon various negative effects found in the literature, several overviews recommend against the use of realistic graphics in a variety of contexts (Renkl & Scheiter, 2017; Smallman & Cook, 2011; Smallman & John, 2005). Smallman and John (2005) even warn of *naive realism*, a supposed folk fallacy resulting in an unwarranted preference for realistic displays (see also Smallman & Cook, 2011). Other authors similarly highlight the downsides of realism (Renkl & Scheiter, 2017), but some acknowledge that there are situations in which realistic graphics are hard to avoid due to specific requirements of a learning task (Scheiter, 2017).

As pointed out by Skulmowski and Rey (2018), comparisons between learning materials differing in their degree of realism run into the problem of using visualizations not only featuring a different visual style but also unequal quantities of information. Therefore, we suggest great caution when interpreting results obtained from studies comparing entirely different visualizations, such as a study by Dwyer (1971). In that study (Dwyer, 1971), heart anatomy was to be learned, among other conditions, using either a highly abstract diagram, a drawing with more detail, a photograph of a model, or a photograph of a heart. Since these learning materials differed in their amount of information and their visual style at the same time, it is difficult to arrive at general guidelines for the use of realism in learning materials from such studies (see also Skulmowski & Rey, 2018).

Importantly, realism has been associated with a higher cognitive load (Brucker et al., 2014; Scheiter et al., 2009). As an example, Scheiter et al. (2009) describe how learners may struggle to find central information in realistic graphics and thus are at risk of experiencing more cognitive load. Similarly, Brucker et al. (2014) identified the potential for distraction due to the intricacy of realistic graphics as a source of cognitive load. In order to more closely discuss the role of cognitive load in learning, we will subsequently present the theoretical framework of cognitive load theory (Sweller, van Merrienboer, & Paas, 1998).

3 | COGNITIVE LOAD THEORY

In the most recent version of cognitive load theory (Sweller, van Merriënboer, & Paas, 2019), the overall cognitive load of a learning task is defined to be the sum of the *intrinsic load* and the *extraneous load* present in a task. The intrinsic load of a task is the result of the complexity and difficulty of the contents themselves and therefore cannot be manipulated by instructional design factors (Sweller et al., 1998). However, extraneous load refers to the cognitive load that is produced by counterproductive design choices concerning the presentation of learning contents (Sweller et al., 1998). Previous research (Brucker et al., 2014; Scheiter et al., 2009) has specifically linked realism to extraneous load and thus, we will concentrate on this facet of cognitive load in the present study.

4 | REALISM AS SIGNALING

Recent research investigating the use of combinations of different degrees of realism has provided evidence for the claim that a high degree of realism will receive more attention from learners (Lin et al., 2017; Lokka & Çöltekin, 2019). Lokka and Çöltekin (2019) compared three different versions of a navigational exercise and found that route memorization performance was best for 3D views of streets that primarily featured simplified buildings and only a few realistic buildings at important places of the route. The two other versions of the learning task contained either only simplified or realistic buildings (Lokka & Çöltekin, 2019). Using the terminology of the field of learning and instruction, such a result could be considered an example of *signaling* (Mautone & Mayer, 2001). Signaling is defined as the use of cues to direct learners' attention and therefore to improve learning performance (Mautone & Mayer, 2001; for recent meta-analyses, see Richter, Scheiter, & Eitel, 2016; Schneider, Beege, Nebel, & Rey, 2018). Several cues have been shown to be effective, such as colors (e.g., Jamet, 2014) and cueing using arrows (Jamet & Fernandez, 2016).

Based on the result of Lokka and Çöltekin (2019) that a mixture of realistic and schematic visualizations can enhance recall performance, we want to assess whether realism can be used as a form of signaling in the context of anatomy learning. Despite the disadvantages of realism concerning cognitive load discussed above, realistic visualizations have been described as being “more engaging and entertaining” (Goldstone & Son, 2005, p. 71) and have been found to be preferable in terms of aesthetics (Lin et al., 2017). Combined with the findings of Lin et al. (2017) regarding the attentional draw of realistic images, we assume that realistic anatomical visualizations capture learners' attention and therefore will result in higher retention scores than schematic visualizations that are presented at the same time. Skulmowski and Rey (2018) previously suggested considering the effect of combining realistic and schematic visualizations in the context of anatomical education based on Lokka and Çöltekin (2019). Consequently, we assume a contrasting effect of realism, meaning that it can lead to higher retention performance due to signaling, while at the same time resulting in higher extraneous load than schematic visualizations (for a summary of the ambivalent properties of realism, see Goldstone & Son, 2005).

5 | DISFLUENCY

Given the contrasting hypotheses formulated above, it may be helpful to consider realism as a form of *disfluency* (as suggested by Skulmowski & Rey, 2018; for overviews on disfluency, see Eitel, Kühl, Scheiter, & Gerjets, 2014; Xie, Zhou, & Liu, 2018). Disfluency occurs when learning materials that impose more difficulty, for instance, due to being less legible (Diemand-Yauman, Oppenheimer, & Vaughan, 2011), actually lead to better learning results than a more legible presentation of contents (e.g., Diemand-Yauman et al., 2011; Experiment 1 in Eitel et al., 2014). In the study of Skulmowski and Rey (2018), a visually more complex realistic depiction of a bone likewise resulted in a high retention performance as long as the model included color cues when compared with versions without details, without color cues, or both.

It needs to be noted that several replication attempts of disfluency research have failed (e.g., Rummer, Schweppe, & Schwede, 2016; see Kühl & Eitel, 2016) and a recent meta-analysis also did not find effects on recall (Xie et al., 2018). Seufert, Wagner, and Westphal (2017) provided evidence for the claim that there is an ideal level of disfluency. In one of their studies, learning performance increased with more disfluent learning materials but dropped as soon as learning materials were too hard to work with due to being less legible (Seufert et al., 2017). The extraneous load was lower for the fluent and more disfluent texts, but higher for the text with the highest degree of disfluency (Seufert et al., 2017). Considering all of these findings, we still assume that the notion of disfluency may help to understand why it is possible to hypothesize paradoxical effects for realism.

6 | THE PRESENT STUDY

Based on the literature discussed above, we have two predictions. We assume that a combination of realistic and schematic visualizations will lead to a viewing preference of the realistic components of the learning materials over schematic parts (in line with Lin et al., 2017); therefore resulting in a higher retention performance for the realistic parts of the learning materials. Furthermore, we expect that a higher degree of realism will lead to a higher extraneous load (based on Brucker et al., 2014; Scheiter et al., 2009).

7 | METHOD

7.1 | Participants and design

The study consisted of a mixed 2 × 2 design (Realism × Diagram). Both groups were presented with learning materials of which one half was a realistic rendering and the other half was a schematic version. The between-subjects factor realism was used to switch the degree of realism on two views of the knee (i.e., side view = realistic, top view = schematic vs. side view = schematic, top view = realistic). As the within-subjects factor, we specified the diagram to which the responses were reacted to (side view vs. top view). Simply put, participants learned with two visualizations of which one was realistic and the other one schematic and then gave their responses (extraneous load ratings and retention performance) regarding both of these visualizations.

This study had 50 participants (37 female, 13 male) based on power calculation using G*Power (Version 3.1.9.2; Faul, Erdfelder, Buchner, & Lang, 2009) at an alpha level of 0.05, power = 0.80, correlation between measures = 0.5, and an assumed η_p^2 = 0.04. The participants were students of Media Communication, Computer Science and Communication Sciences, or Media and Instructional Psychology. They participated in partial fulfillment of course requirements. Participation conditions were an age of 18–30 years, German as their native language, and no to little knowledge of knee anatomy.

7.2 | Learning materials

The learning contents for this study were two visualizations of the human knee, presented as a side view and a top view. For this experiment, we followed the method of manipulating realism by varying the shading and rendering of 3D models while keeping their geometry constant across conditions (similar to Skulmowski & Rey, 2018). The visualizations were created using Blender 2.79b and Inkscape 0.92.4 based on visualizations from Gray (1918) with additional information found in various sources (Bammes, 2009; Karpinski & Petersen, 2017; OpenStax, 2018; Tillmann, 2016). The realistic versions contain detail realized through texture maps and normal maps; while the schematic version was designed to look like a line diagram with minimal detail and only one color per component, rendered using thin black outlines.

Participants were presented with the side view and the top view (Figure 1), one of them was displayed as realistic and the other as schematic. The two combinations of realistic and schematic visualizations (Figure 1a,b) were assigned between-subjects using block randomization, resulting in a balanced distribution. The order of the two images was alternated sequentially between participants to avoid sequence effects.

7.3 | Retention test

Retention performance was measured using a single test in the form of a labeling task. On the test page, the same visualizations that they had learned with were presented to participants, except for the replacement of the label texts with letters (i.e., participants who had learned using the realistic side view and the schematic top view were presented with the same renderings in the testing phase). Their task was to assign the correct component names to the corresponding letters using a drag-and-drop mode of interaction. The learning test for the side view had a McDonald's ω (McDonald, 1999; calculated using JASP Version 0.9.2; JASP Team, 2019) of 0.76, the test of the top view had an ω of 0.86.

7.4 | Cognitive load survey

In this study, we used the extraneous load questions from the survey instrument by Klepsch, Schmitz, and Seufert et al. (2017). It

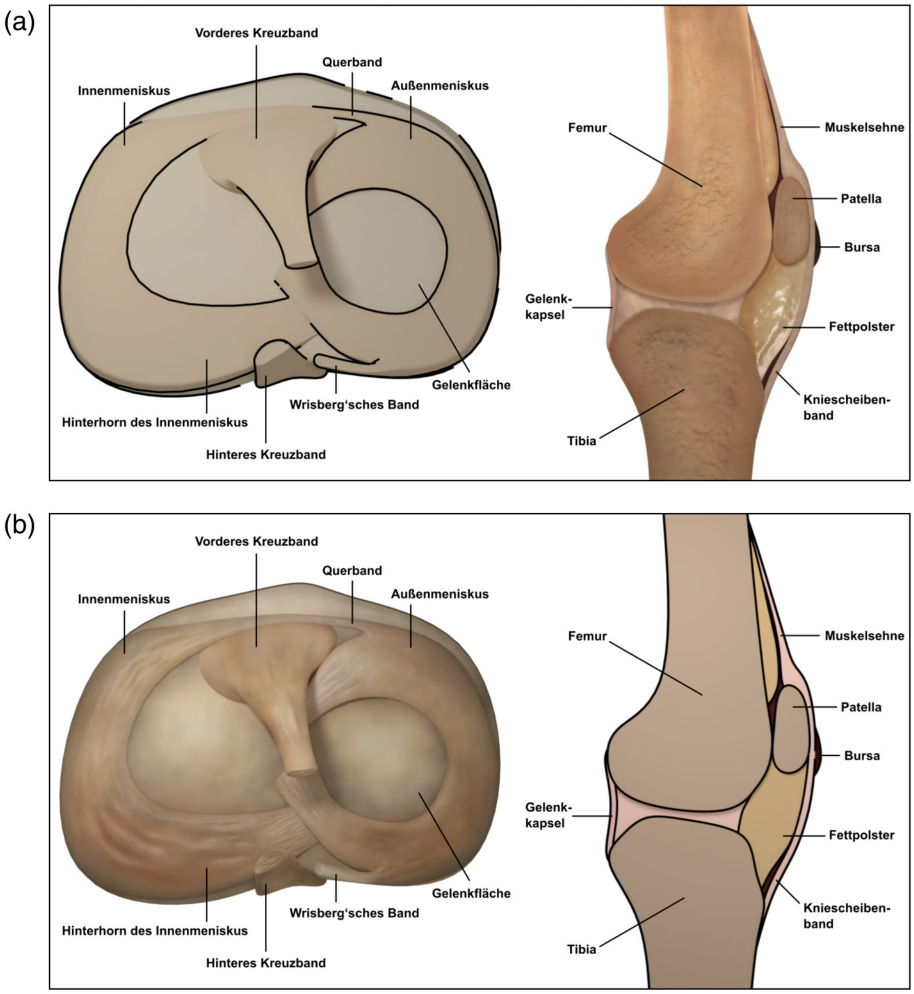

FIGURE 1 The learning materials used in the study. Panels a and b show the two different combinations of the learning materials that were used (based on Gray, 1918, with additional information from Bammes, 2009; Frisch, 2003; Karpinski & Petersen, 2017; OpenStax, 2018; Tillmann, 2016). In panel (a), the side view of the knee (shown on the right side) is presented in a realistic style, while the top view (shown on the left side) was rendered using a simplified, more schematic style. In panel (b), these styles were swapped for the side and top views. In addition, the order of the top and side view was sequentially alternated between participants

was shown that this cognitive load instrument is appropriate for learning using anatomical visualizations that do not feature explanations or other forms of more elaborate verbal contents (Skulmowski & Rey, 2020). However, we replaced the word "Aufgabe" ("task," Klepsch, Schmitz, & Seufert, 2017, p. 10) with "Abbildung" ("visualization") in the three extraneous load items. The extraneous load survey items concerning the side view resulted in an ω value of 0.88, the items asking for the extraneous load of the top view had an ω of 0.90.

7.5 | Procedure

Participants provided their informed consent at the beginning of the experiment. They confirmed that they met the criteria for participation and were asked to specify their course of study (using two options comprised of courses related to media research and an option for other courses) as well as their gender.

The next page contained the instructions for the learning task. Participants were asked to memorize the names, shapes, and locations of the knee components depicted on the images in the following learning task and were informed about the time limit of 60 s. They could not skip to the next page for 15 s to prevent participants from ignoring these instructions. On the following page, both visualizations were displayed together with a countdown of the remaining time. The placement of the two visualizations was counterbalanced across participants.

Then, participants were asked to fill out the two sets of extraneous load questions. The order of these sets of questions corresponded to the order of the presentation; if the side view was presented on the left side, participants were first asked to indicate their cognitive load ratings for the side view, accompanied by a reminder that they saw the side view on the left side of the screen. Participants could not proceed to the following page until 30 s had elapsed to prevent rushed responses. Before the learning tests, a filler task was presented in which participants had 60 s to rank the 16 German federal states according to their area.

On the next page, participants were given labeling tests for the two views of the knee (one below the other). The order and degree of realism matched the order and degree of realism during the learning phase. The test page featured an explanation of the drag-and-drop controls, a statement that there was no time limit as well as a reminder not to use any additional resources.

The last page contained questions asking participants whether noise or other external sources of distraction strongly impeded their learning process (simplified into a binary response from the method used by de Nooijer, van Gog, Paas, & Zwaan, 2013, and Skulmowski &

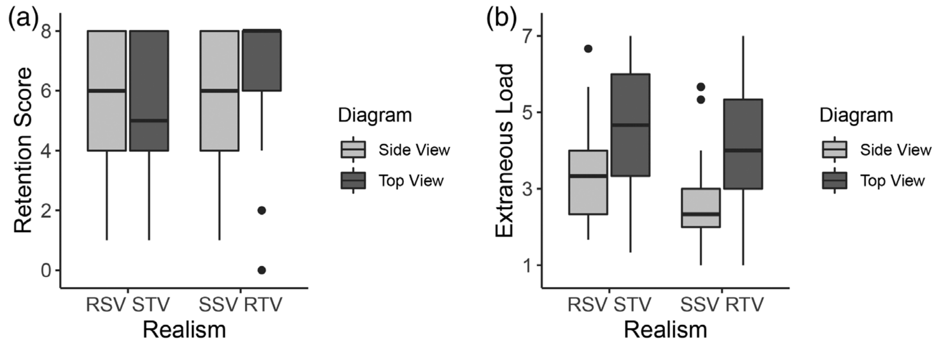

FIGURE 2 The descriptive results of the study (RSV STV = realistic side view, schematic top view; SSV RTV = schematic side view, realistic top view). (a) Boxplot of retention scores with a minimum of 0 and a maximum of 8. (b) Boxplot of extraneous load responses (averaged) with a minimum of 1 and a maximum of 7

Rey, 2018) and whether they encountered major technical difficulties during the learning task (as in the study of Skulmowski & Rey, 2018). Participants were thanked and received further information on the study. The study was conducted using SoSci Survey (Version 3.2.01-i; Leiner, 2019; https://www.soscisurvey.de).

8 | RESULTS

For the analyses of this study, we used two 2 × 2 mixed analyses of variance (ANOVAs) using R (Version 3.6.0; R Core Team, 2019). Plots were created using ggplot2 (Wickham, 2016).

8.1 | Retention performance

As can be seen from the retention data in Figure 2a, there are several outliers in the retention scores. Furthermore, some participants may have used a variety of learning strategies that potentially counteract our experimental manipulation (such as sticking with a rule of learning from left to right and top to bottom while ignoring the visual design). In order to account for the presence of outliers as well as the potential use of atypical learning strategies, we used a robust ANOVA using a trimmed means approach (Wilcox, 2017) computed with the package WRS2 (Version 1.0–0; Mair & Wilcox, 2019).

The 2 × 2 mixed robust ANOVA with 20% trimmed means resulted in a significant interaction effect, $F(1, 26.34) = 4.24$, $p \leq .05$. If the side view was realistic and the top view was schematic, participants reached lower scores on the test of the top view than on the test for the side view. However, if the side view was schematic and the top view was realistic, participants scored better on the test for the top view. Therefore, our hypothesis regarding realism acting as a form of signaling was confirmed; retention scores were higher for the realistic parts of the learning materials.

8.2 | Extraneous cognitive load

The averaged extraneous load data are presented in Figure 2b. We used a 2 × 2 mixed robust ANOVA with a 20% trimmed means for the analysis of the extraneous load data. The interaction effect of realism and diagram did not reach significance, $F(1, 27.44) = 0.12$, $p = .732$. However, there was a significant main effect of the between-subjects factor of realism, $F(1, 28) = 4.66$, $p = .040$. The extraneous cognitive load was overall higher when the side view was displayed as realistic and the top view as schematic. This may be a result of the side view having a higher number of different surface textures and therefore being more attention-grabbing than the top view. Hence, we consider this result as a partial confirmation for our prediction that a higher degree of realism leads to more extraneous cognitive load.

In addition, there was a significant main effect of the diagram, $F(1, 27.44) = 38.93$, $p < .001$, with lower extraneous load ratings being given for the side view. Based on Garg, Norman, Eva, Spero, and Sharan (2002), Stull, Hegarty, and Mayer (2009) distinguish between *canonical* representations that are frequently found in anatomy books and *noncanonical* representations that show anatomical parts in unusual orientations. Perhaps, the top view of the knee resulted in a higher extraneous load due to being a rather uncommon sight for novices.

9 | DISCUSSION

The experiment confirmed our primary hypothesis that realism can act as a form of signaling. All participants were presented with one realistic and one schematic view of the knee; retention performance was higher for the realistic parts of the learning materials. This result is an indication that learners focus their attention on realistic imagery (in line with Lin et al., 2017) and therefore, realism can be used in conjunction with schematic visuals to guide learners (as shown by Lokka & Çöltekin, 2019, in a different context). In addition, we found that extraneous load ratings were higher when the side view was presented realistically; partially supporting our second hypothesis that realistic visuals receive higher subjective extraneous load ratings. Several authors have linked realism with increases in extraneous load (e.g., Brucker et al., 2014; Scheiter et al., 2009). Consequently, we can assume that realism can have a seemingly contradictory effect of aiding learning (at least under some circumstances) while increasing extraneous cognitive load at the same time.

9.1 | Explanations for the realism paradox

The results of the present study can largely be explained using our hypothesis of realism acting as a signaling device while inducing extraneous load due to an added complexity. Disfluency research offers an additional potential building block for a comprehensive model of the effects of realism on learning, such as the idea that disfluent material leads to more extensive cognitive processing (Alter, Oppenheimer, Epley, & Eyre, 2007). In line with the results of Seufert et al. (2017), there may be an ideal level of disfluency, and this level may be attained using realism. Thus, our paradoxical results could be explained using a cognitive mechanism based on signaling and disfluency.

9.2 | Implications for cognitive load theory

As the central assumption of cognitive load theory is that extraneous load is detrimental to learning performance (Sweller et al., 1998; Sweller et al., 2019), the results of our study might pose a challenge for the theory. In light of the paradoxical results, we think that further research may be useful to strengthen cognitive load theory. Recently there have been calls to more strongly, including motivational factors (Feldon, Callan, Juth, & Jeong, 2019) and emotional aspects (Plass & Kalyuga, 2019) in cognitive load theory. Perhaps, these instructional components share a more complex interplay that needs to be uncovered before we can fully explain results such as ours.

9.3 | Implications for the design of visualizations

Taken together with some of the previous results on learning with realistic graphics found in the literature, our results have a wide range of practical implications. Scheiter (2017) lists "the user, the features of the content to be displayed, the context in which the visualization is to be used, and the main objective to be achieved with a visualization" (p. 234) as factors that need to be kept in mind while creating visual learning contents. Based on these dimensions, our study would be classified as featuring young novice learners learning basic anatomical knowledge in a very short time. Thus, there are several real-world scenarios to which our results should be transferable. For instance, educators presenting their students' slides featuring visualizations differing in their degree of realism should consider that their students' attention may be focused on the more realistic images. Conversely, they might deliberately choose more realistic graphics for more important content and schematic diagrams for less important information (similar to Lokka & Çöltekin, 2019). For example, this approach could be beneficial when some parts of an object are merely displayed to provide context and are not the actual learning targets. Likewise, a similar strategy for combining visual styles may prove successful for the design of online learning resources and textbooks. Importantly, our results are highly relevant for the design of virtual reality learning settings. Similarly to the findings of Lokka and Çöltekin (2019), the results could be considered as evidence for an instructional strategy of guiding learners' attention by using realistic representations for key aspects in a virtual environment. However, further systematic research needs to be conducted to assess whether the effect found in the present study can be generalized to other contexts and learners.

It is important to acknowledge that our findings do not necessarily invalidate previous findings concerning the positive or negative effects of realism. The results of the present study, however, extend previous findings on learning biological contents using visualizations that have predominantly featured between-subjects comparisons between realistic and schematic versions of learning contents (Brucker et al., 2014). Instead, we utilized the rarely used approach of combining different degrees of realism (Lokka & Çöltekin, 2019) and suggest that further comparisons in this vein may reveal other positive functions of realism.

9.4 | Limitations

As addressed above, the results may be dependent upon several contextual factors. Follow-up studies with longer learning times, learners with more expertise, and other learning contents need to be conducted to assess the scope of our results. Furthermore, our results might be limited to other situations in which two visualizations differing in their degree of realism are being presented. Further research is necessary to investigate whether other visual characteristics of visualizations attenuate or interfere with the cognitive processes leading to our results. In addition, as the measurement of cognitive load using subjective surveys is known to have issues (Schnotz & Kürschner, 2007), the mismatch between our retention results and the extraneous load ratings may be caused by methodological limitations. Finally, it may be worthwhile to consider the effects of gender in learning with realistic visualizations in future studies. Previous research suggests gender-dependent differences in the cognitive processing of spatial stimuli (Mueller, Jackson, & Skelton, 2008; see Castro-Alonso, Wong, Adesope, Ayres, & Paas, 2019, for a meta-analysis in the context of learning media) and may thus be a factor to be considered when applying our results to the design of visualizations.

10 | CONCLUSION

The results of the present study, taken together with other findings from the literature (Lin et al., 2017), suggest a visual dominance of realistic imagery over abstract visuals. Although there justifiably is abundant criticism of the unwarranted use of realism (Renkl & Scheiter, 2017; Smallman & John, 2005), we emphasize that one should not overlook the potential advantages of realistic graphics. When doing so, the paradoxical nature of realism, namely the beneficial capacity for signaling occurring hand-in-hand with a potential concurrent increase in extraneous cognitive load, needs to be considered.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

A.S. designed the study with critical input from G.D.R. A.S. created the learning materials and conducted the study. A.S. performed the statistical analyses with input from G.D.R. A.S. drafted the manuscript. G.D.R. revised the draft. A.S. and G.D.R. have read and approved the manuscript.

ORCID

Alexander Skulmowski https://orcid.org/0000-0002-1682-021X

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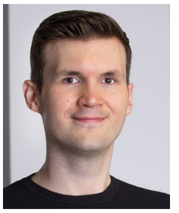
AUTHOR BIOGRAPHIES



Alexander Skulmowski works as a postdoc at the Chair of Psychology of Learning with Digital Media, Chemnitz University of Technology, Germany. In his research, he investigates learning with perceptually rich digital media, including realistic visualizations, embodied learning, and virtual reality. His courses focus on the learner-friendly design of multimedia learning environments and cognitive design aspects.

Günter Daniel Rey leads the Chair of Psychology of Learning with Digital Media at Chemnitz University of Technology, Germany. In his research, he examines several aspects of multimedia learning, including cognition, emotion, and motivation. His teaching is concerned with the aforementioned aspects of learning and instructional psychology.

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