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Realistic details in visualizations require color cues to foster retention

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ABSTRACT

Research on visualizations suggests that realism can be distracting and cognitively demanding, thereby lowering learning performance. These results have been explained using cognitive load theory, assuming that realistic details act as unnecessary mental load. Recent findings from disfluency research, however, imply that under certain circumstances harder-to-perceive learning materials are able to keep learners' attention focused and trigger them to invest more effort. We contrasted these conflicting results by assessing the role of realistic details on learning. For the study, we generated a fictional bone model and varied the level of arbitrary detail (low vs. high). As previous research has revealed positive effects of color coding on visual attention, we used color coding as a second experimental factor (with vs. without) and hypothesized that color coding will primarily help participants learning with a detailed model. We conducted a 2 × 2-factorial between-subjects study (n = 108) and found an interaction between the level of detail and color coding: Highly detailed renderings result in a high retention performance when color coding is available, while color coding on a low-detail model even lowered retention scores. These findings suggest that realistic visualizations require appropriate visual aids in order to be effective.

1. Introduction

Realistic visualizations are frequently found in school textbooks on biology (Wiley, Sarmento, Griffin, & Hinze, 2017) and advances in computer visualization enable the wide-spread use of realistic visual representations in learning materials (Imhof, Scheiter, & Gerjets, 2011). While previous research suggests that simplified visualizations in many cases outperform more elaborate and realistic representations (e.g., Dwyer, 1969; Scheiter, Gerjets, Huk, Imhof, & Kammerer, 2009), a higher degree of detail has been found to be beneficial under specific circumstances (for instance when learners have high spatial abilities as shown in a study by Brucker, Scheiter, & Gerjets, 2014). One problem with research on realism in educational media is that Definitions of realism are generally multi-faceted (see Rieber, 1994, and Dwyer, 1969, for examples of the diversity of suggested components), potentially leading to confounded study designs (Castro-Alonso, Ayres, & Paas, 2016, discuss the problem of keeping visual learning materials comparable regarding their degree of realism). Realistic details are considered to be an important contributor to realism (e.g., Brucker et al., 2014). Therefore, we set out to more closely assess the effect of realistic details in visualizations on learning by creating three-dimensional (3D) renderings of a fictional bone and varying the level of realistic detail. On a theoretical level, we contrasted the perspectives of cognitive load theory (CLT) and disfluency research (following Eitel, Kühl, Scheiter, & Gerjets, 2014). While a CLT perspective generally advises to enhance learning by avoiding irrelevant cognitive load (Sweller, 1988; Sweller, van Merrienboer, &

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Paas, 1998), disfluency effects are aimed at increasing the degree of attention that learners allocate to a given learning task by providing difficult-to-perceive learning materials (e.g., Diemand-Yauman, Oppenheimer, & Vaughan, 2010). More generally, this study was designed to offer a more generalizable answer to the question of how much level of detail is optimal for anatomical diagrams and similar visualizations.

1.1. Realistic details in visual learning materials

Definitions of realism have emphasized the contrast between visualizations with realistic details and abstracted forms of representations such as schematic drawings (e.g., Rieber, 1994; Scheiter et al., 2009). Dwyer conducted a series of studies comparing several forms of realism and schematization, generally finding either no benefit of realistic depictions or even revealing an advantage for learning with less detailed visualizations (e.g., Dwyer, 1967a, 1969, 1971, 1976; for a meta-analysis, see Reinwein & Huberdeau, 1997). Despite the range of possibilities that modern computer graphics offer, recent research confirmed these beneficial effects of schematic representations (e.g., Brucker et al., 2014; Scheiter et al., 2009). However, a study by Imhof et al. (2011) did not result in a significant effect of realism on learning performance. Crucially, some studies found higher learning performances (at least for specific types of tasks) when learning tasks included realistic and detailed visualizations compared with abstract representations (e.g., Arnold & Dwyer, 1975; Dwyer, 1967b; van Gendt & Verhagen, 2001).

Lokka and Çöltekin (2017) compared three different visualization styles in the context of a route learning task. These three visualization styles differed in their level of detail. The abstract visualization consisted of untextured, white, flat shaded models of the route to be learned, while the realistic version added detailed textures of the street and buildings. Interestingly, the study included an intermediate level of detail in which the route was displayed without textures while only a few important buildings were presented with textures. Routes were presented as 3D rendered videos from a first-person perspective. Remarkably, the intermediate version led to the highest recall scores both in long-term and short-term memory tests, regardless of participants' spatial ability. In this experiment, participants were also asked concerning their preference regarding the visual style before and after the learning phase. While most participants indicated that they prefer the realistic version before beginning the learning task, the majority preferred the intermediate form after completing the first set of tests.

It is important to clearly distinguish between the variety of operationalizations of realism (for classifications, see Höffler, 2010 and Höffler & Leutner, 2007). Some studies contrast realistic images such as photographs with schematic representations such as line drawings (e.g., Brucker et al., 2014; Dwyer, 1969). This approach provides opportunities for comparisons between unedited real-word depictions of learning contents and deliberately simplified versions (see Goldstone & Son, 2005, for a detailed comparison). However, one needs to acknowledge that transforming a realistic image into a schematized representation usually requires several design decisions; thus raising doubts whether a comparable amount of information is retained when realistic depictions are schematized (Castro-Alonso et al., 2016; see also Larkin & Simon, 1987, for theoretical considerations regarding diagrams). In order to avoid this issue arising when comparing varying degrees of realism, we chose to isolate a single factor involved in graphical realism, namely the level of detail, and attempted to vary this factor in a controlled manner.

Basic research on the perception of three-dimensional objects suggests that humans process their visual impressions by mentally subdividing their view into more primitive components (Biederman, 1985, 1987). Applied to anatomy learning using visualizations, this approach would assume that we have a tendency towards analyzing complex anatomical shapes in terms of simpler volumes; a process that may be inhibited by the visual complexity induced by details (e.g., Dwyer, 1969; Norman, Todd, & Orban, 2004). As suggested by Scheiter et al. (2009), presenting learners with highly detailed anatomical structures may hinder learning by taking up unnecessary cognitive resources, thereby burdening them with *extraneous load* according to the terminology of CLT (Sweller, 1994; Sweller et al., 1998). In a recent paper on the design of visual learning materials, Renkl and Scheiter (2017) recommend the use of abstracted visuals instead of realistic graphics.

1.2. Disfluency: when demanding design enhances learning

The preceding overview on realism in learning materials suggests that simplified and schematized representations may be easier to visually process and therefore may enhance learning performance (e.g., Scheiter et al., 2009). Conversely, a higher level of detail may be assumed to increase cognitive demands (e.g., Norman et al., 2004). However, the research field of *desirable difficulties* has revealed instances in which learning materials that make learning harder actually enhance recall performance instead of hindering it (Bjork, 1994). A desirable difficulty often investigated using visual stimuli is the disfluency effect (see Alter, Oppenheimer, Epley, & Eyre, 2007, for an overview): Disfluency in multimedia learning may occur when a visually degraded or otherwise hard to visually discern stimulus elicits a higher performance than easier-to-process versions by triggering a more thorough approach of mental processing (Eitel et al., 2014). While CLT aims to enhance learning by reducing unnecessary mental load (Sweller et al., 1998), disfluency research provides reasons to assume that *irrelevant* realistic details may, in fact, improve learning performance (see Eitel et al., 2014, for a related contrast of CLT and disfluency): (a) Adding irrelevant surface detail may let an object appear to be more difficult to learn than a simple, smooth surface (see Eitel et al., 2014, for a similar hypothesis), thereby potentially letting learners invest more mental effort (Alter et al., 2007; Diemand-Yauman et al., 2010); (b) surface detail adds visual interest that may engage learners' attention (Goldstone & Son, 2005; see also Rieber, 1994), thereby potentially promoting the integration of textual and visual information through more frequent eye movements (see Mason, Tornatora, & Pluchino, 2013, for a study on eye movement and learning). Designing learning materials in a way to optimize eye movement patterns was investigated recently within research on multimedia learning in a study by Skuballa, Fortunski, and Renkl (2015). Skuballa et al. (2015) were able to show that an activity