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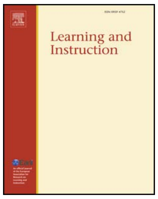

Optimizing learning from animation: Examining the impact of biofeedback

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ABSTRACT

The purpose of this study was to investigate whether EEG biofeedback would help engage learners in obtaining procedural knowledge from animated or static visualizations. Two specific forms of this feedback were investigated. The first was active feedback that required learners to interact with the feedback using hand gestures. The second was constructive feedback that instructed learners to verbally reflect on their learning processes by utilizing the feedback. A total of 116 college students were randomly assigned to one of six experimental conditions formed by a 2 X 3 factorial design with the visualization type (animated vs. static) as one factor and the feedback type as the other factor (constructive vs. active vs. no feedback). The results revealed that learners who received no feedback had significantly higher perceived attentiveness and value than their peers who received constructive feedback. Additionally, when constructive feedback was provided, learning procedural knowledge from animated visualizations reduced perceived difficulty in learners when compared to static visualizations. These findings were discussed in terms of the implications, limitations, and future research directions.

1. Introduction

Dynamic visualizations, or animations, have been increasingly utilized in educational and training settings over recent years. Not only has decades of research demonstrated an overall positive effect of animations, but has also shown a link between animations and specific types of knowledge acquisition (Höffler & Leutner, 2007). Moreover, the animation effect on learning also depends upon a variety of factors (Berney & Betrancourt, 2016). In the current study, we investigated using two specific types of biofeedback to engage learners in the processing of animated visualizations.

1.1. Learning with animations

Animations are a type of visualization that “generates a series of frames, so that each frame appears as an alternation of the previous one, and where the sequence of frames is determined either by the designer or the user” (Bétrancourt and Tversky, 2000, pp. 313). Based on this definition, animations have an advantage over static images in their ability to illustrate conceptual changes, procedures, and dynamic processes. Animations provide external scaffolding for learners to build correct mental models regarding learned knowledge and skills so that learners do not need to make (incorrect) inferences from static graphics.

In the existing literature, two meta-analytic studies have shown the potential benefits of using animations for learning and instruction. Höffler and Leutner (2007) reviewed 26 relevant studies conducted from 1970s to early 2000s, which resulted in 76 comparisons between animations and static pictures. Their analysis revealed a medium-sized effect favoring animations. Furthermore, three factors were identified in their meta-analysis as the moderating factors for the effectiveness of animations. The first is the role of animation. Specifically, animations that are representational in nature were found to be more effective than static pictures. The second moderator is the type of knowledge studied. Using animations was found to be more effective for learning procedural knowledge, as opposed to learning declarative knowledge and solving problems. The third moderator identified by Höffler and Leutner is the degree of realism. Animations with a high degree of realism were found to be more effective than static pictures. Berney and Betrancourt (2016) meta-analyzed 140 pairwise comparisons (animated vs. static) from 50 research reports published from 1976 to 2013. In contrast to the work of Höffler and Leutner, they used Bloom's revised taxonomy to code the outcomes with two dimensions: a cognitive dimension (to remember, understand, apply, analyze, evaluate, and create) and a knowledge dimension (factual, conceptual, procedural, and meta-cognitive knowledge). Berney and Betrancourt found that the positive effects of animation did not vary across different learning outcomes, no matter whether they were factual, conceptual, or procedural knowledge. However, they did find that system-paced animations with audio narrations or without accompanying text were superior to static visualizations. In summary, the results of these two meta-analytic studies are inconsistent and somewhat contradictory.

Recent empirical studies reported in the literature also reveal mixed

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findings in terms of the superiority of animations over static graphics. For instance, Turkay (2016) compared the relative benefits of using whiteboard animations (a type of animated video that demonstrates the drawing processes on a whiteboard to explain concepts or processes) to static images in promoting learners' acquisition of physics concepts. The results showed that the whiteboard animations had positive effects on retention, engagement, and enjoyment. Such positive effects of animation were also found in other recent empirical research, where learners were involved in learning concepts, processes, and procedures (e.g., Castro-Alonso, Ayres, & Paas, 2015; Stebner, Kühl, Hoffler, Wirth, & Ayres, 2017). However, a number of empirical studies have revealed different findings in a variety of learning tasks. For instance, Castro-Alonso, Ayres, and Paas (2014) reported two experiments in which learners were asked to memorize abstract symbols through either animations or static pictures. They found that static visuals were better than their animated counterparts in terms of accuracy and efficiency for a task with a high level of transience (i.e., visible for only 12 s). In an experiment conducted by Wong, Leahy, Marcus, and Sweller (2012), learners were instructed to complete a paper-folding task by viewing either static graphics or animated videos. Their findings turned out to be a little complicated: Animations were found to be superior to static graphics only when instructional materials were presented in short segments; but these two types of visualizations were equivalent in terms of impacting learning when materials were presented in longer segments.

A variety of theoretical accounts have emerged to explain the cognitive processes involved in learning with animations. Specifically, some researchers argue that both perceptual and cognitive processing are involved (Wagner & Schnotz, 2017). Learners initially process animations on the perceptual level by parsing the dynamic flow into separate elements. They later build their mental models by making sense of how these elements operate together (Lowe & Boucheix, 2017). Static and animated visualizations may be equally effective when the learning goal is to understand the composition of a system because both types of visualizations present the key elements or states (Wagner & Schnotz, 2017). Nonetheless, static visualizations may be less effective than animated visualizations when the learning goal is to understand the mechanism of how a system works, since learners may experience more difficulty making correct inferences from static visualizations (Hegarty, 1992). Thus, by externally providing information, animations can reduce a learner's cognitive burden. Other researchers have looked at the animated-static comparison from an embodied perspective. They argue that the mirror neuron system (a system that plays an important role in understanding actions) in humans can be activated during the process of learning procedural knowledge from dynamic visualizations (van Gog, Paas, Marcus, Ayres, & Sweller, 2009). Such learning, triggered by this activation, imposes substantially less mental effort on learners due to its nature of being evolutionary primary knowledge (Paas & Sweller, 2012). De Koning and Tabbers (2011, 2013) further argued that engaging learners in gestures, object manipulation, and other human movements can improve learning from animations. This is because learners' motor experiences related to the content presented in the animation help enhance the construction of their mental models.

1.2. The engagement framework

One critical factor, learner engagement, seems to be missing from the discussion on the animated-static comparison. The mixed findings reported in the existing literature could be attributed to learners' different levels of engagement. Theoretically, engagement is a multi-dimensional construct, which encompasses behavioral, emotional, and cognitive aspects. Behavioral engagement refers to students' participation, attention, and effort. Emotional engagement refers to students' interest, boredom, and other affective constructs. And cognitive engagement refers to the investment of learning (Fredicks, Blumenfeld, & Paris, 2004). This broad and ambiguous conceptual delineation not only shows that intrinsic motivation (e.g., interest, value, and effort) and engagement are reciprocally connected, but also extends engagement to internal cognition (such as cognitive load). According to Blumenfeld, Kempler, and Krajcik (2004), if individuals are focused and interested in the materials or tasks presented in a learning environment, they may be more engaged in the learning processes, which leads to germane cognitive processing and enhanced learning outcome. They also argue that the success of knowledge or skill acquisition may result in their perceptions of competence and value, as well as reduced pressure.

An emergent engagement framework provides a new perspective to explain this inconclusive literature with regard to the animated-static comparison. Based on learners' overt behaviors, Chi and Wylie (2014) distinguish four modes of engagement: interactive, constructive, active, and passive (ICAP). In the passive mode of engagement, learners are seen as the information containers because they only receive information. For example, they just passively listen to lectures or view videos. In contrast, active engagement involves learners' physical manipulation or action, such as pointing to and underlining the reading materials. Furthermore, a learner's engagement can be considered constructive when this individual generates something beyond the presented material, such as self-explaining and summarizing. Finally, interactive engagement refers to the situations when constructive learning occurs in a group of individuals. Chi and Wylie hypothesize that learning outcomes associated with interaction should be better than learning outcomes associated with construction, which is better than activeness, which is superior to passiveness. According to ICAP, merely presenting different types of visualizations without other learning strategies is a passive mode of engagement, as learners neither generate products nor manipulate materials during the learning process. As a result, without the support of other learning strategies, learning outcomes associated with animated and static visualizations should have no significant differences.

The advancement of digital technologies, such as smart phones and tablets, offers great opportunities for educators to engage learners in novel and multifaceted ways. This is especially the case as human movement like gesturing can be applied with the help from these technologies. A recent empirical study conducted by Agostinho et al. (2015) revealed promising evidence in this respect. The researchers asked some primary-school students to trace temperature graphs with their fingers on an iPad while a remaining group of students simply read the graphs without any finger tracing. The study's results indicated that learners who physically traced elements of a graph outperformed their peers who did not on transfer tests. Although using digital technologies has shown its potential of enhancing engagement, it must be noted that providing feedback to learners can also be utilized to further assist learners in correcting any faults in their mental models as well as to monitor their learning processes more effectively.

1.3. Biofeedback in learning and instruction

Feedback is the information a teacher, a peer, a parent, a computer-based environment or other agents provided to improve an individual's learning and performance (Hattie & Timperley, 2007). Feedback has been long recognized by scholars as one of the most powerful techniques in learning and instruction, as learners can benefit from it by confirming or modifying their current mental models (Cohen, 1985). Results from several early meta-analytical studies provide supporting evidence for the effectiveness of feedback (Hattie, 1999; Kluger & DeNisi, 1996). For instance, Kluger and DeNisi meta-analyzed over 600 effect sizes obtained from 131 papers. These papers reported empirical evidence regarding using feedback as a way of intervention. The researchers found that feedback had an overall positive effect on performance with a moderate effect size. However, over one third of such