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Self-generated drawings for supporting comprehension of a complex animation

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ABSTRACT

The perceptual and cognitive processing demands involved in comprehending complex animations can pose considerable challenges to learners. There is a tendency for learners to extract information that is highly perceptually salient but neglect less conspicuous information of crucial relevance to the building of a quality mental model. This study investigated the effectiveness of self-generated drawing for learning from an animation illustrating a scientific phenomenon, the so-called "Newton's Cradle." Participants were 199 students in grade seven, randomly assigned to three experimental conditions: self-generated drawing, traced/copied drawing, and no drawing. All participants were asked to produce an explanation of the animation for both immediate and delayed posttests. The results revealed the superiority of self-generated drawing in supporting animation comprehension at both testing times compared to the other two conditions, which did not differ from each other. In addition, comprehension of the animation was related to the quality of self-generated drawings. Specifically, the depiction of information characterized by low perceptual salience but high conceptual relevance to the phenomenon predicted comprehension and retention over time.

1. Introduction

Educational animations have become an increasingly common feature of learning environments that are supported by technology. Multimedia learning resources and educational websites make extensive use of such dynamic graphics with the aim of supporting students' comprehension of complex materials, especially those that deal with scientific phenomena and systems (Ainsworth, 2006). Animations may serve various purposes (Hegarty, Kriz, & Cate, 2003). They can depict not only visible phenomena but also those that are invisible, such as changes in pressure or temperature as shown in an animated weather map (Lowe, 2004). Animations can also represent more abstract types of content, such as statistical concepts (Bodemer, Ploetzner, Feuerlein, & Spada, 2004), problem solving procedures (Wouters, Paas, & van Merriënboer, 2009), computer algorithms (Narayanan & Hegarty, 2002), or prey and predator relationships (Ainsworth & Van Labeke, 2004).

Although many animations present their referent subject matter realistically, others deliberately distort reality. They do this by approaches such as speeding up some processes and slowing down others, portraying an object or phenomenon from different or changing perspectives, augmenting the display to cue viewers' attention to more relevant parts, or making moving objects leave tracks. These very different mappings between referents and dynamic visualizations make it difficult to generalize findings from one type of animation to another (Hegarty, 2004).

Some evidence in the literature indicates that dynamic graphics may have advantages over static displays, particularly with respect to student motivation and implicit learning (Rieber, 1991; Rieber, Tzeng, & Tribble, 2004) or the learning of procedures (Höffler & Leutner, 2007). However, there is mounting contrary evidence indicating that the effects of animation on learning are not uniformly positive. For example, the review by Tversky, Morrison, and Bétrancourt (2002) identifies cases where there are no benefits for animation over static graphics. Further, studies reporting an advantage for animation may be confounded by the presence of accompanying verbal information. A compelling case therefore exists to investigate learning from animations *alone* in order to provide a scientific account of how they are comprehended *per se*, without help from verbal accompaniments (Boucheix & Lowe, 2010; Hegarty, 2004; Lowe, 2003, 2004).

Despite equivocal research evidence about animation's effectiveness as a tool for learning (Bétrancourt, 2005), more and more reliance is being placed on animated graphics. Given that this take-up of animations seems unstoppable, the question then arises as to what approaches could be adopted to improve learning from these representations? Recent research identifies the importance of using strategies that encourage learners to process the information provided in animations more deeply (Kombartzky, Ploetzner, Schlag, & Metz, 2010; Rebetez, Bétrancourt, Sangin, & Dillenbourg,

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2010). Such approaches typically use *verbal* instructions that direct students to carry out a series of steps as they study an animation. However, another more *visually*-oriented strategy that has come into prominence of late with respect to informational texts is "drawing-to-learn" in which students generate their own graphic representations to aid their developing understandings. This approach has been seen as having particular relevance to science education, with Ainsworth, Prain, and Tytler (2011) suggesting that learners' drawing should be valued (along with writing, reading, and talking) as a crucial component of science learning.

Embedded in the theoretical framework of the Animation Processing Model (APM; Lowe & Boucheix, 2008, 2011), the present study examines the potential of self-generated drawing to invoke deeper processing of animations by requiring learners to engage in constructive, transformative manipulation of the presented content in order to support their extraction of relevant information, irrespective of its salience. According to the APM, perceptual aspects of processing play a key role in learning with animations so that careful observation of the depiction is absolutely central to success. Requiring learners to generate explanatory drawings of the events depicted in an animation should enhance their extraction of information in general and less perceptually salient information in particular. However, comprehension requires that effective information extraction and internalization is accompanied by appropriate cognitive processing that facilitates the construction of a high quality mental model.

The study reported in this paper extends recent research on the effects of self-generated drawing on learning from texts by investigating its effects on the comprehension of a science animation. The next sections review issues relevant to the use of drawing as a learning strategy and to the comprehension of animations.

1.1. Drawing as a learning strategy

Learner-generated drawing is the "construction of an external visual representation, or picture, of to-be-learned content" (Van Meter, Aleksic, Schwartz, & Garner, 2006, p. 143). This definition has been developed to include the requirement that learners should "maintain responsibility for the final appearance of drawings and the constraint that final drawings are representational" (p. 143), that is, "drawings are intended to show how depicted objects actually look" (p. 143). Research indicates that when learners create their own visualizations (instead of only interpreting others' external representations), scientific learning is facilitated (Ainsworth et al., 2011). The effectiveness of self-generated drawings in supporting learning from science texts has been attributed to the benefits that come from externalizing one's own cognition (Cox, 1999). Van Meter (2001) compared the effectiveness of three approaches for supporting fifth and sixth grade students' learning from a text about the nervous system: drawing instructions only, drawing instructions with additional supports, and illustrations with no drawing instruction. Students who produced their own drawings recalled more from the text than those who saw illustrations but did no drawing.

Beneficial effects of self-generated drawing were also found with regard to problem-solving performance, particularly if the drawing activity was supported (van Meter et al., 2006). In a study by Schwamborn, Mayer, Thillmann, Leopold, and Leutner (2010) of ninth graders learning the chemistry of washing, students who received drawing instructions with prompts performed better than a control group with neither drawing instruction nor prompts.

A series of small-scale studies by Ainsworth (2010) investigated how students could use drawing more effectively when learning from texts about the cardio–vascular system. Participants were asked to self-explain the text content before drawing, or to draw for different audiences (i.e., for themselves or a peer). The results indicated that learners' drawing activity can be enhanced by strategies that stimulate their active processing of the learning material before they represent their new understandings in drawings.

Two recent studies by Leopold and Leutner (2012) compared the effectiveness of self-generated drawing not only with a control group, but also with groups using verbal strategies that required learners to invest effort but via a non-visualization activity (Experiment 1: selection of main ideas; Experiment 2: summarizing). Participants were tenth graders learning about water molecules from a chemistry text. Both studies revealed a clear superiority of drawing over verbal activity. In addition, the cognitive advantages of drawing were found for transfer tests but not for multiple-choice tests of factual knowledge. The finding that self-generated drawing is particularly beneficial for deeper learning is consistent with the outcomes of previous studies (Van Meter et al., 2006).

In all the above studies, self-generated drawing was examined with respect to learning from text (albeit, sometimes illustrated text). To our knowledge, only two studies have been carried out to investigate the effects of drawing on learning from a dynamic visualization. The content for both of these studies was the chemical reactions that occur in hydrogen fuel cell cars. In the first, Zhang and Linn (2011) compared drawing with giving students more time to explore the visualization. Eighth graders who generated their own drawings to interpret the animation integrated more ideas than peers who explored the learning material for a longer period. In the second study, Zhang (2010) compared the effectiveness of having high school students generate drawings with having them produce a critique of pre-existing drawings. Those who generated drawings were better able to distinguish amongst different ideas and to acknowledge the flaws in their representations than students who produced the critique.

Why is drawing-to-learn effective? Van Meter et al. (2006) describe learner-generated drawing in broad terms as an "elaborative, strategic" activity that "should lead to the construction of a mental model" (p. 144). More specifically, the Generative Theory of Drawing Construction (GTDC) proposed by Van Meter and Garner (2005) concerns the role of drawing in learning from text accompanied by illustrations. It identifies a number of important processes that could be facilitated if learners generate drawings while studying such materials. We will suggest that with one exception, the processes identified in the GTDC should also be applicable to learning from animation as investigated in the present research. That exception is integration because the animation involved is not accompanied by any form of text so learners are not required to integrate information from two different types of representation. As will be discussed below, the remaining processes fostered during drawing of (i) selecting key elements from a provided external representation, (ii) organizing those key elements into groups, and (iii) constructing an internal representation appear likely to benefit learning from animation.

The beneficial effects of drawing on learning from illustrated text are attributed to its role as a recursive activity in which there are mutual influences amongst the various internal and external representations available to the learner (Van Meter et al., 2006). The recursions involved support learner processes such as self-monitoring that can expose misunderstandings and redirect attention to hitherto neglected key aspects of external representations. Although this account targets illustrated text, in principle it appears possible that the learner's repeated cycling back and forth between an animation and an evolving drawing could serve similar functions. However, this would require the activities supported by drawing (i.e., selection, organization, and construction) to be of value not only to learning from illustrated text, but also to learning from animations. In the next section we explore this possibility by considering some challenges to learning from animation, the likely origin of these challenges, and the extent to which the