Computers in Human Behavior 64 (2016) 497–506

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Full length article

The role of spatial ability when fostering mental animation in multimedia learning: An ATI-study

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ARTICLE INFO

Article history:
Received 26 February 2016
Received in revised form
14 July 2016
Accepted 18 July 2016

Keywords:
Multimedia learning
Cognitive load
Mental animation
Spatial ability
Aptitude-treatment interaction
Johnson-Neyman significance region

ABSTRACT

The present Aptitude-Treatment-Interaction (ATI) study investigates the learner characteristic spatial ability (aptitude) and the variation of mental-animation prompts (treatment: no vs. mental-animation prompts). A group of high-school students ($N = 94$) learned about a biology topic through learner-paced multimedia instruction. Some of the learners received mental-animation prompts and others learned without prompts. A fine-grained analysis with spatial ability as continuous aptitude variable and mental animation as treatment showed a positive learning effect of animation prompts in learning outcomes of processes, but not in knowledge about structures. In addition, spatial ability only modified the relationship between animation prompts and learning when analyzing knowledge about processes. Specifically, only learners of low to medium spatial ability profited from the prompts while learners with very low or high spatial ability had comparable results when learning with or without prompts. In addition, only learners with high spatial ability rated their cognitive load to be significantly higher when learning with prompts. Results align with the assumptions of the production deficiency of learners with low to medium spatial ability, mediation deficiency of learners with very low spatial ability and stable learning performance of learners with high spatial ability whatever the learning situation offers.

1. Introduction

Recent research on multimedia learning investigates how learners construct dynamic mental models of visual-spatial learning content. Hegarty, Kriz, and Cate (2003) as well as other research (Hegarty, 1992; Schwartz & Black, 1996) has shown that people are quite successful in inferring motion from static diagrams. This process is named mental animation, which is associated with two main insights: (1) if all components of the learning material move at once, people tend to mentally animate each component in order of the causal sequence of events and (2) people tend to initiate a process of internal visualization like mental rotation when learning with multimedia instruction that includes textual and pictorial parts. The process of mental animation has been shown to occur through the use of eye tracking (Hegarty & Just, 1993; Hegarty, 1992). Eye movements indicate that learners verify the motion of a system component by inspecting a specific individual component as well as the components that precede the specific component, indicating a more global understanding of the causal chain of events.

In addition, other studies indicate that learners' spatial ability is highly related to their ability to engage in mental animation (Hegarty & Kozhevnikov, 1999; Münzer, Seufert, & Brünken, 2009; Sims & Hegarty, 1997). Research suggests that low and high spatial ability learners use the similar strategies to mentally animate learning material, but that low spatial ability learners are less accurate (Hegarty & Sims, 1994). It can be assumed that instruction should increase low spatial ability learners to engage in a more accurate and effective process of mental animation. Therefore, the research question of the current study examines how learners with low spatial ability can be supported to mentally animate static learning information in order to profit from visual motion information and increase their learning performance.

To this end, the goal of the present study is to develop mental animation prompts that foster learners' ability to mentally animate complex learning information. Through an aptitude-treatment interaction design, differences in the effectiveness of the mental

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http://dx.doi.org/10.1016/j.chb.2016.07.022
0747-5632/

animation prompts (treatment) for the continuous (aptitude) variable spatial ability will be examined using a fine-grained analysis in order to define the region of sensitivity for this treatment.

2. Theoretical framework and predictions

2.1. External and internal (mental) animation in problem solving and multimedia learning

When learning within the technologically advanced environments of today, it is often assumed that the construction of dynamic mental models is facilitated. For instance, computer-based material or web-based learning tools make it possible to extract complex process information from external animations (e.g. videos). Within such learning environments, processes and the causal chains between components of a process are directly observable which should facilitate learning. In particular, learners should profit because they are able to construct a high-quality mental model, which includes the possibility of mental animation (Johnson-Laird, 1983). In particular, the ability to manipulate a mental model by running it for- and backwards should be increased when a visible external animation is present. In sum, animations should be intrinsically superior to static graphics.

However, experimental research on animation leads to inconsistent results. With the superiority of external animations over static pictures supported by a range of studies aggregated into a meta-analysis by Höffler and Leutner (2007); in contrast, this superiority of learning with animations was not seen in a synthesis of 20 studies by Tversky, Morrison, and Bétrancourt (2002). With their finding indicating that the majority of the 20 studies did not confirm that external animations foster learners in comparison to static graphics within a wide range of learning domains including physics, computer interactions, biology and mechanics. Tversky et al. (2002) concluded that some of the reviewed studies lacked comparable conditions. For example, the content between static and animated graphics did not elicit the same content knowledge, as was the case with studies conducted by Rieber (1990, 1991). Unfortunately, studies of this nature were included in the meta-analysis by Höffler and Leutner (2007) and may be the underlying mechanism for the inconsistent finding between the two syntheses.

Due to the inconsistent results it remains unclear as to when external animations support learning and when they do not. One potential reason why external animations are not always superior to static graphics could be the demands that are put on visual short-term retention and attentional control when learning with external animations. For example, an animation that provides relevant information but disappears as the animation progresses (Mayer & Chandler, 2001) may require more effortful control by the learner. Moreover, the development of misconceptions can actually be induced when learners work with external animations due to passive and perfunctory processing. This sort of processing can lead to the illusion of understanding the whole process without having mentally extracted and integrated necessary elements needed for the construction of a dynamic mental model.

The need to support learners' development of dynamic mental models raises an additional question of how to best present dynamic information that includes complex textual and pictorial representations that can be extracted and integrated into a dynamic mental model. The goal of the present study, therefore, is not only to investigate the learners' differences in inferring from static learning material, but also to answer the question how to foster learners to start an active process of mental animation. To support this effort, three different possibilities are discussed on how to present dynamic information in order to reach the latter goal.

2.2. Three ways to foster engagement in an active process of mental animation

2.2.1. Presenting a sequence of key events

In an experiment, Hegarty et al. (2003) showed that the presentation of critical phases of an operating system in the format of static pictures induces performance-enhancing activities. Learners who only saw three critical phases of the operating system without any additional learning text achieved an equivalent comprehension performance when compared to learners who learned with an external animation. This aligns with research on mental representations of continuous processes, which indicates that people try to mentally represent processes as a sequence of key events rather than simulation of continuous motion (Zacks & Tversky, 2001). This result leads to the conclusion that screenshots of the most relevant steps of a process can be chosen as a performance-enhancing support for mental animation.

The advantage of such static information could be that learners have to actively process the stepwise information in order to mentally represent the process information. Aggregating the static steps into a global process may construct a high-quality dynamic mental model as passive and perfunctory processing of the given information is avoided. To benefit from the static information learners need to mentally extract and integrate necessary elements for the construction of their personal dynamic mental model to understand the given learning task. Moreover, learners who are fostered to construct their own mental model should be able to detect and correct misconceptions during the active processing. Thus, static stepwise instruction of key events should not only stimulate the construction of a mental model in a more appropriate way than external animations, but also induce fewer misconceptions due to the required active and generative processing.

2.2.2. Enriched static pictures

Another possibility for fostering learners' active processing of information is the use of so-called enriched static presentation. These presentations show discrete steps with additional information about processes, for example an enriched presentation may include arrows as a hint to mentally animate the cued element of the learning material (Münzer et al., 2009). With the support of such enriched static presentations the learner is guided to mentally animate the static information. The effectiveness of such enriched static presentations is demonstrated in an experimental study by Münzer et al. (2009), resulting in the conclusion that they are as effective or even more effective as an external animation in the format of a video.

Moreover, in contrast to learning with the external animations, spatial abilities were crucial for learning with enriched static pictures (Münzer et al., 2009). As provided in the enriched static pictures condition, even learners with high spatial abilities needed some support in the visual channel to successfully learn by means of mental animation with static pictures. This leads to the conclusion that enriched static pictures may initiate an active visuospatial processing. The activation of such processing may also reduce the risk of producing an illusion of knowing (Glenberg, Wilkinson, & Epstein, 1982). Enriched static presentations have to be actively processed, in other words, enriched static presentations like the presentation of key events avoids passive and perfunctory processing.

2.2.3. Prediction task

The third possibility of presenting information is providing learners with instructions to predict subsequent events. Hegarty et al. (2003) tested the effect of studying an animation after having tried to predict the behavior of the operating system from static