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Making Instructional Animations More Effective: A Cognitive Load Approach

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SUMMARY

This themed issue consists of seven empirical papers, as well as an introduction and discussion, and has its genesis in three symposia, organised by the authors of this article and presented at the 2006 Annual Meeting of the American Educational Research Association (AERA) in San Francisco, California. The papers investigate a number of conditions under which instructional animations may be effective. This article uses cognitive load theory (CLT) to provide an explanation for why animated instructions have not currently produced the learning benefits expected. A brief overview of the papers with a focus on how they accommodate critical aspects of cognitive load is given. The issue finishes with a discussion on each paper and identifies some common principles and recommendations for instructional design and research into animations. Copyright © 2007 John Wiley & Sons, Ltd.

Animated instructional materials (i.e. dynamic representations) are an enigma. Whereas, it is easy to intuitively forecast a number of situations where animations might be particularly effective, for example learning situations that involve motion, the research base has often failed to provide convincing evidence of any advantage. Most of the reviews have not found animation to be any more effective than the equivalent static graphics (e.g. Hegarty, Kriz, & Cate, 2003; Schnotz, Böckheler, & Grzondziel, 1999; Tversky, Morrison, & Betrancourt, 2002). Furthermore, experiments by Mayer, Hegarty Mayer, and Campbell (2005) have found that in some environments, such as learning about mechanical systems, static diagrams can be superior to animated equivalents. These findings paint a somewhat depressing picture and raise the following concern—from a learning perspective how can present computer technology, with its immense power, availability and sophistication, be no better, or sometimes worse, than pages in a book? This is an important question to answer, as much of contemporary society expects modern technology to provide great benefits to educational environments. As a result, research into animated instructional environments has become a significant focus in recent years.

A number of reasons have been proposed for the relative ineffectiveness of animation. For example, Koroghlanian and Klein (2004) found that participants who received

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animation as opposed to static illustrations spent more time studying the information, with no corresponding gains in terms of learning. Lowe (1999, 2003) has suggested that perceptually salient features may attract learners' attention away from the more-subtle but thematically relevant features of animations. Furthermore, Mayer et al. (2005) have argued that statics allow more active processing (often referred to as mental animation) as learners are required to make inferences from frame to frame instead of making passive observations. Some commentators, such as Ayres, Kalyuga, Marcus, and Sweller (2005) and Ploetzner and Lowe (2004), have argued that animations place greater cognitive load demands on the learner than corresponding static presentations. Presently there is no theory that explains all the cognitive processes involved in learning from animations (Chandler, 2004), however, because of the increasingly held viewpoint that cognitive load is a significant factor, cognitive load theory (CLT) may provide some insights.

Many of the authors in this collection of papers use CLT, or aspects of it, as their main theoretical argument. Consequently, in this introduction we give a brief outline of CLT, and identify some of the key factors about animations that have direct consequences for a learner's cognitive load. Finally we classify each of the papers in terms of how they have been designed to take account of cognitive load issues.

The central tenet of CLT is that the interaction between long-term memory (LTM) and working memory (WM) has a significant role in learning. Whereas the capacity of LTM to store information is extremely large, WM is very limited both in duration and capacity (see Miller, 1956; Peterson & Peterson, 1959). However, the limitations of WM only apply to new information that has not been previously learned (Sweller, 2003, 2004). Cognitive load theorists argue that knowledge is stored in LTM in the form of schemas (Chi, Glaser, & Rees, 1982). These knowledge structures allow multiple elements of information to be treated as a single element when brought into WM; hence expanding its capacity and allowing more complex learning to occur. However, instructional procedures that ignore the limitations of WM, either by presenting too much novel material, or by creating a learning environment where scarce WM resources are taken up by the instructions themselves, are likely to be a major impediment to learning. Over 2 decades CLT has used this view of the human cognitive architecture to identify a number of principles for designing instructional materials effectively (see Sweller, 2004 for a review).

CLT identifies three categories of cognitive load (see Paas, Renkl, & Sweller, 2003; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Ayres, 2005). *Intrinsic cognitive load* is the 'natural' load imposed by the information that must be acquired. It consists of interacting elements that must be processed simultaneously in WM to understand and learn new material. *Extraneous cognitive load* is the load imposed by the instructional procedures themselves. It is under the control of the instructional designer. *Germane cognitive load* refers to the WM resources required to acquire information (schema construction). If extraneous load is high, learning is likely to be impeded, however, any reduction in extraneous cognitive load frees up WM capacity that can be devoted to activities that are relevant to learning and understanding, that is induce germane cognitive load.

It is plausible that many animated instructional environments are not as effective as expected because they create a high extraneous cognitive load. As previously reported, if animations are designed in such a way that they distract the learner's attention away from essential information, learners are forced to conduct searches to find the relevant information. The process of locating the important information creates extraneous cognitive load because precious WM sources may be diverted away from the main learning

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focus. Furthermore, as pointed out by several authors in this issue, animations can be highly transitory in nature. If information disappears from the screen as the animation progresses, learners may be forced to process current information while trying to remember previous information, raising cognitive load. In these circumstances, animation produces an extraneous cognitive load. In contrast, static graphical displays can be revisited a number of times by the learner, hence eliminating the problem associated with transitory information.

If animations increase extraneous cognitive load specific strategies are needed to support them, otherwise learning will not be facilitated. To compensate for the transitory effect, a logical strategy is to allow the learner to stop the animation, or to divide it into smaller parts. Previous research by Mayer and Chandler (2001) found that both learner control and segmenting were beneficial in an animated environment. WM overload was avoided by giving the learner the facility to control the pace at which information was presented or segmenting the information into smaller parts. Similarly, extraneous load can be reduced if the learner's attention is more directed within complex animations rather than requiring the learner to make searches without additional help. Support for this argument has been found by other researchers who have found annotations (Wallen, Plass, & Brünken, 2005), cueing (Harp & Mayer, 1998) and attention guidance (Betrancourt, 2005) effective in an animated environment.

The authors in this themed issue continue the research of identifying strategies to make animated instructions more effective. Five of the seven papers directly address the issue of lowering extraneous load. Two by using a user-control strategy and three by using a cueing (signalling) and/or segmenting techniques. Consequently, it is useful to group these papers together into two categories called—*reducing extraneous cognitive load-user control* and *reducing extraneous cognitive load-cuing and segmenting*. The final two papers take a different approach as they both directly try to induce germane cognitive load, rather than focusing on reducing extraneous load. Consequently these papers are grouped together under the heading—*Promoting germane cognitive load*.

REDUCING EXTRANEOUS COGNITIVE LOAD-USER CONTROL

The first paper by Cheryl Cohen and Mary Hegarty required participants to perform spatial inference tasks on a three-dimensional object. To assist in this task, two user-controlled animations, which rotated the object either around its horizontal or vertical axis, were available to the problem solvers. This within-subject design explored the relationships between spatial ability, animation use and task performance. Unlike the other papers in this collection, participants were asked to solve problems rather than learn some new content. As problem solving can increase extraneous cognitive load (Sweller et al., 1998), the auxiliary animations provided a tool that could potentially lower this load by making the problem-solving task easier.

The second paper by Béatrice Hasler, Bernd Kersten, and John Sweller investigated the influence of user (learner) control in an animated environment designed to teach primary school students about the science behind 'day and night'. In a four-group design, two groups had user-control over an instructional animation, whereas two groups experienced system-based controls. For the user-control environments, one group was presented the animation in discrete whole segments, which they were able to start after each segment finished; the second group viewed a continuous animation, which they were able to stop

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and re-start at the learner's control. In contrast the third group viewed the animation continually without any stopping facility. The fourth group received a continuous presentation consisting of narration only, whereas the other three groups had both narration and visual representations. Extraneous load was reduced automatically for the group, which received the segmented animation and potentially for the group that had the stop/start facility.

REDUCING EXTRANEOUS COGNITIVE LOAD-CUING AND SEGMENTING

It should be noted that in some cases in the following studies, participants were required to start presentations; however, there was no facility to stop them at any stage. All the dynamic representations or segments ran continuously, and therefore these studies were not considered interactive.

The third paper by Björn de Koning, Huib Tabbers, Remy Rikers, and Fred Paas investigated the impact of cueing in an animated environment. In this study, which compared two groups, participants were required to learn about the main processes involved in the cardiovascular system. One group received a visual cue on one specific process—how the heart valves work, whereas the second group received no such cue. An additional focus of this experiment was to investigate how both groups answered questions on the non-cued processes of the cardiovascular system, as well as the cued content (heart valves).

The fourth paper by Mary Lusk and Robert Atkinson investigated the influence of two variables in an animated environment. The first variable, consisting of three conditions, examined the impact of a pedagogical agent, which guided the learners through a learning episode on mathematical word problems. The pedagogical agent consisted of a cartoon-style parrot, which in the most guided condition directed the learner's attention to a specific problem state by gaze, gesture and movement, as well as providing oral elaborations. For the least guided condition, there was no cartoon character, but simply a voice-over, which provided a commentary. The second variable compared two forms of worked examples. The first form, in the more traditional format, provided a fully worked example displaying all the steps in the solution path simultaneously in a split-screen design separate from the animated learning episodes. In contrast, the second format provided worked examples where each step in the solution was presented one-at-a-time, controlled by the learner. Even though, the learner has some control in this group, it is control over the worked example, and not over the instructional animation. From a CLT perspective both variables under investigation include conditions which will reduce extraneous load. The agent by directing the learner's attention and avoiding unnecessary searches and the gradual introduction of the worked-example by matching the precise solution steps simultaneously with content of the animation.

In the fifth paper Roxana Moreno investigated whether signalling (cueing) and/or segmenting dynamic representations (in both a video and animated format) would lead to superior performance in learning about seven classroom teaching skills. In a video/animation presentation, which demonstrated applications of the teaching skills, segmenting was achieved by dividing the video/animation into equal segments, presented one-at-a-time. Signalling was achieved by cueing the particular teaching skill being applied at any stage during the presentation by highlighting the relevant skill from a permanently displayed list. Four groups (segmented + cued, segmented + non-cued,

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non-segmented + cued, non-segmented + non-cued) were compared with each other as well as with a control group, which focused on the theoretical aspects of the teaching skills rather than the applications.

PROMOTING GERMANE COGNITIVE LOAD

The sixth paper by Fred Paas, Pascal Van Gerven, and Pieter Wouters investigated the impact of making predictions on segments of the animation. In a three-group design all the participants were shown the same animated instructional presentation on how the cardiovascular system works. Following this presentation, each group was shown a number of key frames taken from the animation and presented as static diagrams. One group were simply shown all the static diagrams simultaneously and asked to study them. In contrast, the other two groups were presented a single frame one at-a-time and either asked to predict the next or previous frame. In this fashion, germane cognitive load was promoted by requiring learners to respond to a set of stimuli taken directly from the animation.

The seventh paper by Richard E. Mayer, Krista DeLeeuw, and Paul Ayres adapts the classic memory paradigm of retroactive and proactive interference to more meaningful instructional materials rather than more artificial learning environments associated with previous studies. In one treatment condition, additional, but related material, is added to the learning environment on a mechanical system (how hydraulic brakes work) in an attempt to induce analogical reasoning (germane cognitive load). In contrast, a second treatment condition has no additional information added. Since the expanded condition had the potential to induce interference, as well as analogical reasoning, both retroactive and proactive interference phenomena were measured. Furthermore, to investigate the impact of animated materials, a direct comparison was also made between computer-based materials (animations) and paper-based materials (statics).

The final paper in this collection is a discussion by Paul Ayres and Fred Paas on the seven empirical papers. Each paper is summarised and some critical observations made and directions for further research identified. Based on the overall research findings in the themed issue a number of recommendations are made for developing effective instructional animations. In addition a number of key design issues are discussed that may enhance future studies in this field.

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