Commentary

The crucial role of cognitive processes in the design of dynamic visualizations

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The development of new technologies allows for endless instructional possibilities in terms of dynamic visualizations for learning. The widespread use of PC technology and more recently web based and e-learning instructional platforms has led to highly dynamic and interactive instructional packages that can be easily accessed by many learners simultaneously. However, despite this seemingly endless potential and unbridled enthusiasm for technology based instruction, there is little empirical evidence to indicate that the widespread use of dynamic visualizations has resulted in any substantial benefit to learners. This situation is probably best summarized by Lowe (2004) in his discussion of the proliferation of internet based animations (a very popular form of dynamic visualization). He notes that “... this explosion in the use of animation is occurring well in advance of adequate research based accounts of how people cognitively process and learn from such resources” (Lowe, 2004).

Instructors have frequently made the crucial mistake of allowing technology to generate the learning experience rather than using our growing knowledge of cognitive processes to guide us in how we can best utilize technology for instructional purposes. Fortunately, this situation is slowly changing. Researchers are starting to make major inroads with respect to our understanding of human cognitive architecture and processes and how this knowledge can best be used to design effective dynamic visualizations (Kalyuga, Ayres, Chandler, & Sweller, 2003; Kirschner, 2002; Lowe, 2003; Mayer, 2001; Mayer & Chandler, 2001; Mayer & Moreno, 2002; Ploetzner, Bodemer, & Feuerlein, 2001; Sweller, 1999; van Merriënboer, Schuurman, de Crock, & Paas, 2002). The papers contained in this special issue represent a very significant addition to the research base on cognition and its implications for technology based instruction. Before commenting on the new and...
viable approaches to dynamic visualizations discussed in this issue, I will briefly summarize the cognitive structures and processes that are central to the research in this area.

As discussed, it has been clear for some time that any approach to instruction that ignores cognitive processes is likely to be deficient. Extensive research has consistently shown that the role of working memory and long term memory and the interaction between the two structures plays a crucial role in learning. Instructional techniques not only need to be sensitive to the severe processing limitations of working memory but also should give due consideration to those activities that will direct resources to the construction and transferability of knowledge held in long term memory. Three sources of cognitive load can be imposed on learners when studying dynamic representations (Kirschner, 2002; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer et al., 2002). Intrinsic cognitive load is a function of the complexity of a dynamic visualization as well as a learner’s prior knowledge (see Sweller & Chandler, 1994). Extraneous cognitive load is determined by how a dynamic visualization is presented to learners or the activities required of learners that are not directly related to learning. Germane cognitive load is generated by mental activities that are directly relevant to the construction and automation of knowledge in long term memory. The remainder of this paper will address the major findings of the research contained in this special issue and their implications for the presentation of dynamic visualizations.

Bodemer, Ploetzner, Feuerlein, and Spada (2004) examined methods of improving dynamic visualizations not only by reducing extraneous load but also inducing germane cognitive load by utilizing interactive activities that are directly related to learning. Specifically, they confirmed that integrated instructional formats (Chandler & Sweller, 1991, 1992), where diagrammatic and textual aspects of dynamic visualizations are presented in a physically integrated format were superior to conventional dynamic visualizations which display text and visual components separately. Integrated instructional packages can aid learning by reducing extraneous load on working memory. The authors also demonstrated that having learners engage with dynamic representations, by allowing them to actively integrate symbolic and static versions of pictorial representations, also led to significant improvements in learning. It should be noted that the interactive exercises involved in the Bodemer, Ploetzner, Feuerlein, and Spada (2004) study were designed only to increase germane cognitive load and therefore the exercises were directly related to learning. Highly interactive learning environments are not always beneficial to learning (e.g., Sweller & Chandler, 1994). Very frequently, interactive computer based exercises involving dynamic visualizations induce heavy extraneous cognitive load by requiring learners to engage in extensive activities quite unrelated to learning. The huge numbers of multimedia instructional packages that consist of endless highly interactive exercises do little but cognitively overload learners and are of limited instructional use. In short, interactive activities will be useful if they are specifically related to learning and also take into account the knowledge base of the learner (Kalyuga et al., 2003).
A great deal of the research in the area of dynamic representations has been conducted using animations. Mayer and his colleagues have been very influential in this area and have provided research based instructional guidance on how we can best utilize animations to take into account the cognitive processes of the learner (for a summary see Mayer, 2001; Mayer & Moreno, 2002). More recently, Lowe, 1999, 2003 has taken the field a step further by exploring how different animations can fulfill their instructional potential without overloading the processing limitations of learners. Lowe (2004) allowed learners to utilize a very flexible interactive facility to more closely examine changes in complex weather pattern systems. However, domain novice users found the facility to interact with and interrogate animations quite unhelpful. Since the learners did not have sufficient background to know what aspects of the animation required further interrogation, they engaged in unsophisticated interactions with the animation and did not extract essential thematic information. The author concluded that animations need to be carefully designed to address processing considerations if meaningful learning is to occur. This work is very much in accordance with work by Mayer and Chandler (2001). Using storm formation animations they found that allowing the user to simply control the amount of information presented in an animation (by examining individual frames separately) could result in lower processing loads and improved learning. The work of both of Mayer and Lowe has demonstrated that animations can be very useful educational tools provided they are designed with sensitivity to the processing limitations of working memory and the experience of the learner.

Hyperlinked videos represent a rapidly growingly method of presenting complex dynamic visualizations. Hyperlinked videos consist of digital videos which are interconnected with hyperlinks, which are freely available to learners throughout the instructional experience. Learners may access through hyperlinks further useful information such as a photo or text related to the video presentation. Zahn, Barquero, and Schwan (2004) note that while the technology is being widely used by instructors there are few cognitively based guidelines by which to effectively structure hyperlinked videos. By combining Mayer’s temporal contiguity principle (see Mayer, 2001) and aspects of cognitive load theory (Chandler & Sweller, 1991), the authors compared four hyperlinked video presentations with a control video presentation that contained no hyperlinks. The authors predicted that presentations that implemented hyperlinks, which ensured spatio-temporal contiguity (thus reducing temporal split attention) would be advantageous to learners. Unfortunately, the study revealed no significant differences in terms of knowledge acquisition or learner preference between the five instructional groups. However, correlation analyses indicated that a more frequent use of the interactive video function and therefore more active participation by users led to a higher understanding of the instructional material. While encouraging, there is clearly a need for further research to examine the cognitive factors that are involved in complex interactive video presentations.

Schwan and Riempp (2004) examined the conditions under which user interactivity could assist the acquisition of knowledge. The authors compared traditional non-interactive with interactive video instruction using knot tying mate-
rial. Interactive participants could utilize the stop, replay, reverse and speed func-
tions to interact with video presentations. As with the Mayer and Chandler (2001)
studies, the opportunity to control and interact simply with dynamic representa-
tions allowed for the more rapid acquisition of knowledge by controlling the flow
of instructional information. The authors concluded that as long as interactive
activities do not over burden cognitive load, interactive videos can result in more
effective learning. Rieber, Tsang, and Tribble (2004) also examined the usefulness
of interactive dynamic representations using computer based simulations with
science materials. Utilizing dual coding theory (Paivio, 1990), the authors demon-
strated that interactive instructional procedures which encourage referential process-
ing led to a deeper understanding of science principles.

Ainsworth and Van Labeke (2004) make the important distinction between the
terms dynamic representation and animation which are often mistaken as synonym-
ous by many in the field of instruction. The authors propose three methods of
representing phenomena that change over time. They are time-persistent, time-
implicit and time singular representations. All three representations have different
consequences for processing limitations with time persistent and time implicit
representations usually being more complex than time singular representations.
Using population density simulations the authors assert that all three types of
dynamic representation have distinct advantages over static representations. The
implications of this work raise issues that hopefully will be addressed in future
research. For example, which types of dynamic representations best support lear-
ners and how can they be combined to result in enhanced understanding of
dynamic visualizations?

It is clear from the above discussion that the design of dynamic visualizations
requires an appreciation of the cognitive mechanisms that underlie complex
thought. Instruction that is oblivious to cognitive factors is likely to be deficient
and unhelpful to learners. The research presented in this issue demonstrates that an
appreciation of the cognitive factors can result in more flexible and effective meth-
ods of presenting dynamic visualizations.

References

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