Cognitive Processes and Visualization

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As a cognitive psychologist, my interest in visualizations has grown out of my previous research background in text comprehension and my overarching interest in human learning. Research in text comprehension has revealed a great deal about how people learn from text and about the complex, interacting factors that can predict a learner's ultimate comprehension (Butcher & Kintsch, 2003). However, text is a very simple type of material given the diverse media options that are increasingly available in learning situations. The use of visualizations in science learning highlights the potential of multimedia resources; visualizations represent a richer set of resources (extending far beyond text and even static pictures) that can support new learning activities. Opportunities for authentic discovery learning is just one example of the ways in which visualizations or other multimedia can provide a learning experience that is fundamentally different from traditional print materials.

Despite the promise of and excitement about visualizations for learning, relatively little is known about how individuals think or learn with visualizations and multimedia. As complex visualizations are increasingly used and available, more research is possible. But in order for visualizations to be optimally designed and applied in learning situations, we must know more about the cognitive processes involved in learning with visualizations. We also must study whether (and how) specific aspects of visualizations impact comprehension processes. My research approach specifically concerns the ways in which experts, intermediates, and novices process visualizations during learning and whether visualizations may be designed to scaffold cognitive processes necessary for comprehension.

In previous research (Butcher, 2004), I studied the cognitive processes and mental models of learners using visual diagrams in addition to a text. Participants studied with more or less detailed diagrams or text only. The more detailed diagrams emphasized correct structural information about the domain (the human heart and circulatory system) and the less detailed diagrams were simplified to emphasize functional relationships. The presence of diagrams significantly increased the number of inferences produced by participants, but did not influence any other (measured) learning process – monitoring, paraphrasing, or elaboration. In addition, participants who used diagrams demonstrated greater mental model development but the effect was most pronounced for students using the simplified diagrams. The interpretation of these results was that appropriately

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designed diagrams can successfully promote learning because they successfully guide the learner to engage in cognitive processes essential for comprehension.

Other research also has supported the conclusion that successful visual resources support important cognitive processes. Ainsworth and Loizou (2003) found that students using diagrams generated more self-explanations and, consequently, learned more than students using only text. Narayanan and Hegarty (2002) have demonstrated that multimedia presentations supporting their proposed model of multimodal comprehension (Narayanan & Hegarty, 1998) facilitate learning to a greater extent than do presentations that do not match the cognitive model. Although these studies approach the issue from different theoretical and methodological approaches, the conclusions are similar: visual resources must effectively support specific cognitive processes in order to promote learning.

The previously mentioned studies use relatively simple visualizations as a form of multimedia. However, geoscience education often involves more complex visualizations that may pose unique questions and challenges. For example, the function of animation in learning from visualizations is an open issue. An excellent review on this topic is provided by Tversky, Morrison, and Betrancourt (2002). These authors point out that existing research on visual animation is far from conclusive; most previous work has confounded interactivity with animation and has failed to ensure informational equivalency in multiple presentations.

Another issue raised by Tversky et al. (2002) is the issue of perception, specifically that complex visualizations can be difficult to perceive and interpret. Indeed, studies of perception and visualizations (Lowe, 1999, 2003) have shown that perceptual features of visualizations can interfere with successful comprehension. Although Lowe (2003) did find an advantage for predictions drawn from animation, the advantage was limited to perceptually salient features. Lowe (1999) also found that novice learners often were distracted by perceptually salient features of an animation at the expense of more important content information. Thus, the interpretation and use of visualizations may be greatly affected by perceptual qualities of the visualization as well as by the expertise of the individual. Understanding how learners with different background knowledge perceive, process, and use visual information (particularly from complex visualizations) are fundamental issues that form the current focus of my research agenda. Specifically, I am interested in the use of visualization by experts and the cognitive processes that must be supported for lower-knowledge students to achieve meaningful learning with visualizations.

Scientists at the National Center for Atmospheric Research (NCAR) use visualization tools for a variety of scientific tasks. Example visualizations produced at NCAR can be explored on the Visualization and Enabling Technologies website (http://www.vets.ucar.edu/). Currently, I am beginning exploratory work to assess when and how NCAR scientists use visualization in their work. More formal work is also planned to assess differences between the cognitive processes of experts, intermediates, and novices as they work with visualizations, with the intention that this work will highlight cognitive processes that must be scaffolded for novices in order to promote meaningful learning. My work also deals closely with the Digital Library for Earth System Education (DLESE: www.dlese.org). As a digital library tool, DLESE provides multimedia content – including visualizations – in its available resources. At the present time, I am reviewing the extent to which DLESE resources conform to design principles from existing multimedia research. Ultimately, we also plan to test comprehension performance with DLESE resources based on cognitive principles of learning.

It is clear that much needs to be learned for successful use of visualizations in education and that collaboration between researchers, educators, and developers will be necessary to better understand when, how, and why to use visualizations. But it is equally clear that the potential impact of visualizations in science education makes the effort worthwhile.

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