Chapter 10
How Revisions to Mathematical Visuals Affect Cognition: Evidence from Eye Tracking

Virginia Clinton
University of North Dakota, USA

Jennifer L. Cooper
Wesleyan University, USA

Joseph E. Michaelis
University of Wisconsin – Madison, USA

Martha W. Alibali
University of Wisconsin – Madison, USA

Mitchell J. Nathan
University of Wisconsin – Madison, USA

ABSTRACT

Mathematics curricula are frequently rich with visuals, but these visuals are often not designed for optimal use of students’ limited cognitive resources. The authors of this study revised the visuals in a mathematics lesson based on instructional design principles. The purpose of this study is to examine the effects of these revised visuals on students’ cognitive load, cognitive processing, learning, and interest. Middle-school students (N = 62) read a lesson on early algebra with original or revised visuals while their eye movements were recorded. Students in the low prior knowledge group had less cognitive load and cognitive processing with the revised lesson than the original lesson. However, the reverse was true for students in the middle prior knowledge group. There were no effects of the revisions on learning. The findings are discussed in the context of the expertise reversal effect as well as the cognitive theory of multimedia learning and cognitive load theory.

INTRODUCTION

Eye-tracking measures may provide important insight into the design of learning materials (i.e., instructional design; Hyönä, 2010; Mayer, 2010; van Gog & Scheiter, 2010). This view is based on the eye-mind assumption (Just & Carpenter, 1980), which states that the eye fixates on what the mind is processing (Just & Carpenter, 1976; Rayner, 1998). By examining what a student’s eyes fixate on, one can discern what that student is focusing on, and this information may be useful for understanding how students use instructional materials.

DOI: 10.4018/978-1-5225-1005-5.ch010
One distinct benefit of eye-tracking measures is their spatial precision, which allows for understanding how information in different regions of a lesson is processed (e.g., Chang & Choi, 2014; She & Chen, 2009). For this reason, eye-tracking measures are particularly valuable for understanding how different representations, such as visuals and text, are processed (e.g., Mason et al., 2013; Scheiter & van Gog, 2009; Schwonke, Berthold, & Renkl, 2009). In this research, we used eye tracking to examine how variations in visuals affect students’ processing of a lesson.

Researchers and curriculum designers have articulated instructional design principles (also called evidence-based principles and cognitive principles) that specify how visuals should be integrated with text (Mayer & Moreno, 1999; Mayer, 2008). The broad aim of these principles is to optimize learning (e.g., Mayer, 2009; Sweller, Ayres, & Kalyuga, 2011). In this work, we used eye tracking to examine students’ processing of a lesson that was either well aligned or less well aligned with these principles.

To address this issue, we used a lesson from Connected Mathematics 2 (CMP2; Lappan, Fey, Fitzgerald, Friel, & Phillips, 2006), which is rich with visuals, such as pictures, diagrams, and other spatial representations (Clinton, Cooper, Alibali & Nathan, 2012). However, the ways visuals are used in the lessons and activities do not always make effective use of students’ cognitive resources. In a separate, large-scale study, a team of researchers has revised the visuals based on instructional design principles, and is testing the revised version of the CMP2 curriculum in a nation-wide randomized control trial in order to determine the effectiveness of the revisions on learning (Davenport, Kao, & Schneider, 2013).

Building on previous research findings on instructional design principles and eye tracking (e.g., Johnson & Mayer, 2012; Ozcelik, Karakus, Kursun, & Cagiltay, 2009; Ozcelik, Arslan-Ari, Cagiltay, 2010), we conducted an eye-tracking experiment with students who read a lesson derived from the CMP2 curriculum with original visuals or with visuals that were revised on the basis of instructional design principles. The aim was to assess the effects of the revised visuals on students’ processing of the different representations and on their subsequent learning. Specifically, we were interested in how eye-tracking measures could reveal the moment-by-moment effort in working memory, referred to as cognitive load, as well as the amount of time spent viewing representations, referred to as the amount of cognitive processing (see Ozcelik et al., 2010 for a similar approach).

**BACKGROUND**

The instructional design principles that guided the revisions are grounded in the cognitive theory of multimedia learning (Mayer, 2009; Mayer & Moreno, 2003) and in cognitive load theory (e.g., Paas, Renkl & Sweller, 2003; Plass, Moreno, & Brünken, 2010). A central idea of both theories is that the structure of the cognitive system imposes limits on the processing of information presented to auditory, linguistic, and visual sensory processing channels that influence how learners integrate information. The cognitive theory of multimedia learning holds that visual and verbal information (i.e., text or speech) are processed in different pathways, and the theory emphasizes the need for the information in these two pathways to be integrated (Mayer, 2014a). In addition, the cognitive theory of multimedia learning prescribes guidance for instructional design, namely the reduction of extraneous (i.e., unnecessary) processing to improve learning (Mayer, 2009). In sum, implementing these theory-based principles in a lesson should reduce the amount of cognitive processing necessary to understand a lesson.

In contrast to the cognitive theory of multimedia learning, cognitive load theory emphasizes the different types of cognitive load (i.e., effort in working memory) a student may experience (Sweller et al.,...