Chapter 11
Optimizing Students' Information Processing in Science Learning:
A Knowledge Visualization Approach

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ABSTRACT

This chapter discusses a theoretical framework for designing effective visual learning in science education. The framework is based on several theories related to cognitive visual information processes and empirical evidence from authors' previous research in visual-based science learning. Emphasis has been made on the structural part of the framework that allows dynamic linking to critical factors in visual learning. The framework provides a new perspective by identifying the variables in visual learning and the instructional strategies aiming at the improvement of visual performance. The discussion of the theoretical and practical significance of the framework is made, followed by suggestions for future research.

INTRODUCTION

There have been genuine concerns about the decreasing of the numbers of students opting to study science in schools (Kennedy, 2014; Scogin & Stuessy, 2015). Studies have shown that the diminishing student population in science can be largely attributed to the following factors: (1) the difficulty of the subject characterized by abstract concepts and complex computation, (2) the dated instructional pedagogy that often lands in students' information overload, and (3) the disconnection between the science subject and the real world. (Savasci Acikalin, 2014; Sokolowska, de Meyere & Folmer, 2014).

Over the last several decades efforts have been made to improve student performance including strategies to promote cognitive and motivational aspects in science learning (Azevedo, 2015). Of particular

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interest to researchers is the use of visual tools to facilitate cognitive information processes in science. For example, Chen and Yang (2014) investigated the relationship between visual tools and students' problem solving skills in science, and found a close correlation between the two. Similar findings were obtained by Liben, Kastens, & Christensen (2011) who studied students' learning in geology. Several learner-centered strategies have been proposed including inquiry-based learning (Gillies, Nichols, & Burgh, 2011) and self-regulated learning (Tang & Neber, 2008; Zimmerman, 1998, 2001) where learners are nurtured to develop high level thinking skills such as making inference and transferring knowledge to a new domain in visual-based science learning. Nonetheless, students may still experience frustration or fail to accomplish the learning goals if the design of above learning does not take into consideration the impact of various cognitive load in visual learning. That is, failing to consider the constraints of cognitive load in visual-based science learning may have serious consequences in learners' performance, especially when visuals cause redundancy or split attention in learning (Mayer, 2001). The purpose of the current chapter is to examine the functional role of visual representations by focusing on (1) the effects of cognitive load on visual learning and (2) instructional strategies targeting at reducing irrelevant cognitive load and increasing relevant cognitive load. By reading this chapter, the readers will be able to:

1. Identify challenges of cognitive loads in visual information processing.
2. Understand pedagogical strategies to reduce cognitive load in learning.
3. Be familiar with the visual learning framework in science learning.

THEORETICAL BACKGROUND

Over the last several decades, educators, psychologists and cognitive scientists have been interested in understanding the cognitive resources in working memory and their relations with visual learning (Paivio, 1986; Sweller, van Merrienboer, & Paas, 1998; Um, Plass, & Hayward, 2012). According to Mayer (2001), cognitive resources play an important role in successful performance in visual learning. Complex cognitive processes in learning such as association across domains, information retrieval from long-term memory, and engagement in deep learning, are closely related to cognitive resources in working memory (Johnson & Mayer, 2009; Paivio, 1986; Zheng, 2007). Several theories have contributed to the understanding of the role and function of cognitive resources in visual learning. They include working memory theory, dual-coding theory, cognitive theory of multimedia learning and cognitive load theory. A discussion of each theory in relation to cognitive resources in visual learning follows.

Working Memory Theory

When discussing cognitive resources, one would invariantly associate it with the epic theory of working memory by Baddeley and Hitch (1994). Based on their empirical findings pertaining to human information processes, Baddeley and colleagues (see Baddeley, 1986, 2000; Baddeley & Hitch, 1994) proposed a working memory model that includes a central executive system with three parts: phonological loop, visuospatial sketchpad, and episodic buffer. The phonological loop stores verbal content, whereas the visuospatial sketchpad caters to visuospatial information. The episodic buffer is a mechanism in working memory that dedicates to linking information across domains to form integrated units of visual, spatial and verbal information with time sequencing such as the memory of a story or event. Overloading any