

Chapter 2

Design Factors for Effective Science Simulations: Representation of Information

Jan L. Plass

New York University, USA

Bruce D. Homer

CUNY, USA

Catherine Milne

New York University, USA

Trace Jordan

New York University, USA

Slava Kalyuga

University of New South Wales, Australia

Minchi Kim

Purdue University, USA

Hyunjeong Lee

University of Seoul, Korea

ABSTRACT

We argue that the effectiveness of simulations for science education depends on design features such as the type of representation chosen to depict key concepts. We hypothesize that the addition of iconic representations to simulations can help novice learners interpret the visual simulation interface and improve cognitive learning outcomes as well as learners' self-efficacy. This hypothesis was tested in two experiments with high school chemistry students. The studies examined the effects of representation type (symbolic versus iconic), prior knowledge, and spatial ability on comprehension, knowledge transfer, and self-efficacy under low cognitive load (Study 1, N=80) and high cognitive load conditions (Study 2, N=91). Results supported our hypotheses that design features such as the addition of iconic representations can help scaffold students' comprehension of science simulations, and that this effect was strongest for learners with low prior knowledge. Adding icons also improved learners' general self-efficacy.

What makes computer animations and simulations effective instructional tools for learning science? We currently see a growing excitement about

using simulations, microworlds, and games to learn and teach, yet there are also voices who are concerned about the potentially high cognitive

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load involved in learning from such exploratory environments (Kirschner, Sweller, & Clark, 2006). Evidence is mounting that the effectiveness of visual environments for learning depends on a variety of design factors, including the information design and interaction design of the materials, and the level of cognitive load they impose. This paper will focus on one of these design factors, namely the type of representation chosen by the designer to depict key concepts in the simulation.

There is a wealth of research suggesting that the design of learning materials, including instructional simulations, must be consistent with the nature of human cognitive architecture and take into account limitations of our perceptual and cognitive systems (Mayer, 2001, 2005; Plass, Homer, & Hayward, 2009; Sweller, 1999). One such limitation is the capacity of working memory (Miller, 1956). Cognitive load theory (CLT) describes two different sources of cognitive load for learning materials that compete for the limited working memory resources of learners: *intrinsic cognitive load* and *extraneous cognitive load* (Sweller, 1999). Intrinsic load refers to the processing of essential information and is determined by the complexity of the material to be learned. Intrinsic load is often described as the level of element interactivity in learning materials, i.e., as the number of items a learner has to hold in working memory in order to comprehend the material. Extraneous load refers to processing non-essential information and is determined by the design of the instruction and the presentation of the materials, which includes the instructional format as well as the format of the representation of information (Sweller, 1999). Instructional designers aim to reduce extraneous cognitive load, especially in situations when intrinsic cognitive load is high.

Much of the research on cognitive load has been done on verbal materials or combinations of visual and verbal materials, showing that in order to be effective, temporal and spatial arrangements of the information, as well as the modality of the

verbal information (e.g., narration versus on-screen text) must be taken into account (Brünken, Steinbacher, Plass, & Leutner, 2002; Brünken, Plass, & Leutner, 2003; Kalyuga, Chandler, & Sweller, 1999; Mayer, 2001; Rieber, 1991; Sweller, 1999). However, verbal and visual materials differ in significant ways that affect the amount of cognitive effort required to process information in these two formats. Whereas verbal information consists of discreet symbolic representations that are processed sequentially, visual information is inherently relational and its elements can be encoded simultaneously (Clark & Paivio, 1991). Because we are interested in identifying design factors for effective simulations, we focus in the present paper on cognitive load induced by visual materials.

Recent research in cognitive science and neuroscience has dramatically improved our understanding of how visual information is processed. Current working memory models include separate cognitive systems – the visuo-spatial sketchpad and the phonological loop – for processing visual and verbal information (Baddeley, 1986). There is a large body of research on the processes involved in the perception and comprehension of visual information (Levie, 1987; Winn, 1994), and for specific types materials, such as charts, graphs, and diagrams, effects of the design of visual displays on comprehension are well understood (Shah & Hoeffner, 2002; Winn, 1991). Researchers have studied the comprehension of graphics and pictures (Schnotz & Kulhavy, 1994; Willows & Houghton, 1987) and how learning scientific information from diagrams, maps, and charts can be more effective than learning from text (Guthry, Weber, & Kimmerly, 1993; Hegarty & Just, 1993; Kosslyn, 1989; Levie & Lentz, 1982; Mandl & Levin, 1989; Shah & Carpenter, 1995; Winn, 1991). Much less empirical research is available on the design of educational simulations.

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