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Learning from multiple representations: An examination of fixation patterns in a science simulation

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ABSTRACT

The present study examined how the integration of multiple representations in a multimedia simulation was associated with learning in high school students ($N = 25$). Using eye-tracking technology, we recorded fixations on different representations of the Ideal Gas Laws, as well as transitions between them, within a computer-based model that included a gas container with animated gas molecules, control sliders to adjust different gas variables, and a graph depicting the relations between the variables. As predicted, fixation transitions between conceptually related parts of the simulation were associated with different learning outcomes. Specifically, greater transition frequency between the gas container and the graph was related to better transfer, but not comprehension. In contrast, greater transition frequency between the control sliders and the graph was related to better comprehension, but not transfer. Furthermore, these learning outcomes were independent of learners' prior knowledge, as well as the frequency and duration of fixations on any individual simulation element. This research not only demonstrates the importance of employing multiple representations in multimedia learning environments, but also suggests that making conceptual connections between specific elements of those representations can have an association with the level at which the information is learned.

1. Introduction

How do learners construct knowledge from a computer-based high school chemistry simulation with multiple representations of key information? In particular, how do the different representations in a simulation contribute to learning, and how do learners integrate these representations to construct knowledge? Answers to these questions are of significance to the design of related learning environments, such as simulations and games, and have the potential to improve instruction and learning of scientific topics as well as advance the development of theoretical models of learning with multiple representations. Our first question is concerned with determining which components of science simulations are associated with student learning, and focuses on different modes of representing information in a visual explanatory model and a corresponding graph. Our second question is concerned with the issue of how learners integrate multiple representations while engaging in a science simulation and how that integration relates to different types of learning. To address these questions, we examined fixation patterns across multiple representations in a chemistry simulation and their relation to measures of learning.

The main goal of this study was to begin investigating specific aspects of the process by which learners construct knowledge when presented with learning environments that include multiple representations of complex subject matter. We aimed to extend research on learning from multiple representations, which has been primarily concerned with learning outcomes, by also focusing on the process of connecting multiple representations. In our study, high school students explored a simulation about the Ideal Gas Laws that contained multiple representations of key information (see Fig. 1). One representation was an explanatory model based on the Kinetic Molecular Theory of Matter. The representation depicted a container with moving gas molecules (depicted as spherical particles), and included control sliders that learners used to manipulate values of three variables: the pressure of the gas, the temperature of the gas, and the volume of the container. The other

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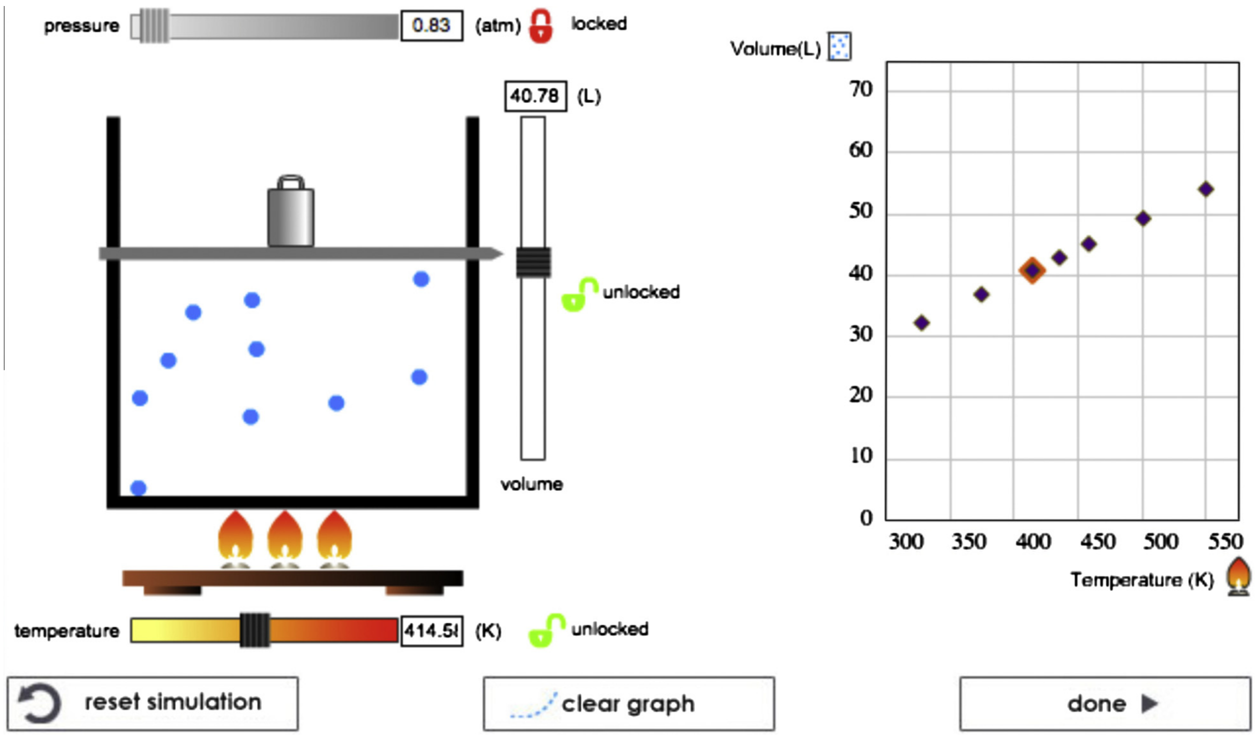

Fig. 1. Interactive model of the Ideal Gas Laws (left) with graphical representation (right).

representation, a graph, was a symbolic representation of the systematic relations between the variables that used a diagram to display all data points generated by the user's manipulation of the simulation. Using eye-tracking technology, we examined the frequency of fixation transitions between conceptually related elements of the simulation. Furthermore, we measured learning in two ways, using separate tests for comprehension (i.e., were learners able to connect key concepts from the simulation?) and knowledge transfer (i.e., can learners apply knowledge to novel situations?).

In this paper, we first describe the exploratory simulation environment used for the present research. We then review extant research on learning with multiple representations and outline the theoretical framework for the present work, which consists of elements from the Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2005; Moreno & Mayer, 2007), the DeFT framework for learning with multiple representations (Ainsworth, 1999), as well as some elements related to cognitive load (Plass, Moreno, & Brünken, 2010; Sweller, 1988), from which we will derive the hypotheses for our research. Finally, we will detail the design of the present study.

2. An exploratory simulation environment for learning high school chemistry

The simulation used for the present research was designed for high school science students (see Fig. 1). It presents a model of the Ideal Gas Laws, which describe how pressure, volume, and temperature predict the behavior of gases for which all collisions between particles (i.e., atoms or molecules) are perfectly elastic and in which there are no attractive forces between them; that is, an ideal gas.

The left panel of the simulation consists of a container with moving gas particles as well as corresponding sliders that allow users to adjust the three variables: pressure, volume, and temperature. Taken together, these visual elements, the simulation engine, and associated variables constitute an explanatory model for the Ideal Gas Laws (Plass et al., 2012). For example, a student might hypothesize that an increase in gas temperature would result in higher pressure of the gas when the volume is kept constant. When the student modifies the temperature to test this hypothesis, the simulation responds by showing the impact of this temperature increase on the pressure of the gas. The increase in temperature is shown through the position of the slider and the numeric value for temperature on the slider, and through the increase of the number of Bunsen burner icons below the gas container. Higher temperature also leads to faster movement of the particles in the container. The corresponding increase in pressure is shown through the position of the pressure slider and the value for pressure on the slider, and through the increase of the number of weights on top of the gas container, and the student would be able to observe this change and compare it with his or her hypothesis.

The right panel of the simulation shows a graph that displays all data points generated by the users when they manipulate the variables of the simulation. The graph constitutes a symbolic representation of the systematic relations between pairs of the variables (Bertin, 1983). Each time the learner modifies a variable by moving the slider in the simulation, the corresponding value pair is added to the graph. Students were asked to explore the relations among pressure, volume, and temperature of an ideal gas by manipulating two of the variables of the simulation at a time, while keeping the third variable constant.

The design of the simulations and the instructions for learners that accompany them are the result of an extensive program of research in which we have investigated cognitive load effects of different simulation designs (Lee, Plass, & Homer, 2006), studied the effects of the icons used to represent pressure and temperature (Homer & Plass, 2010; Plass et al., 2009), and verified the efficacy of the simulations in the high school classroom (Plass et al., 2012). We will next describe the theoretical foundation for the simulation design and the present research.