Mental Models and Computer-Based Scientific Inquiry Learning: Effects of Mechanistic Cues on Adolescent Representation and Reasoning About Causal Systems

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This research applies cognitive science to the development and study of computer-based scientific inquiry learning. A scientific inquiry software program designed in the domain of elementary hydrology was adapted for mental model reasoning research, and tested in two middle school science classes. The study explores how qualitative mechanistic cues about system factors influence mental animation of system mechanisms and reasoning about causality. Middle school groups were compared on model development, inquiry, prediction, and learning. Students provided with mechanistic cues during inquiry developed more complex models with significantly more animated explanations of how and why causality exists. When not provided with mechanistic information, students reduced the level of complexity and animation in models during inquiry. Girls started with more complex and animated models than boys and reduced the level of complexity and animation in models during inquiry, whereas boys increased the level of complexity and animation in models. Students provided with mechanistic cues had more accurate theories after inquiry than students not provided with mechanistic cues. There was a trend toward use of better inquiry strategies and more accurate prediction in girls provided with mechanistic cues. Level of animation in model descriptions was a significant predictor of developing accurate theories.

KEY WORDS: scientific-inquiry; educational-technology; cognition; reasoning; system-studies; learning.

INTRODUCTION

Einstein and Infeld (1938, cited by Zukav, 1979, in Johnson-Laird, 1983) liken our effort to know reality of trying to understand the mechanism of a closed watch. The face and moving hands are seen. The ticking is heard. But there is no way to open case. They suggest an “ingenious” act would be to “form a picture of a mechanism which could be responsible for all observed.” Einstein and Infeld imply intelligent scientific discovery involves constructing a mental representation of an external mechanism to account for individual observations.

The goal of this experiment is to investigate whether providing mechanistic cues would induce greater complexity and mechanistic representation of factors and relations in mental models, leading to advances in reasoning and learning. Can mechanistic cues designed to elicit mental depiction of mechanistic qualities of system components facilitate generation of “correct” qualitative mental animations of system mechanisms? Do inquiry programs providing representational pieces of a system under investigation lead to greater visualization of more pieces in a model and better reasoning? Mechanistic cues hinting at how to represent components and causal relations between components would lead to more integrated causal models made up of subcomponent models in mental representation. Constructing a cohesive mental structure accounting for observations and illustrating explanations
for observations could provide an organizational framework for making inquiries and inferences about observations.

Craik (1943) presents the notion of a mental model as an internal representation of a system. According to Johnson-Laird (1983), people rely on mental models to make deductions (Johnson-Laird, 1983; Johnson-Laird and Byrne, 1991), and reasoning could be based on semantic rather than syntactic method of formal rules. Content of premise can affect deductive performance (Wason and Johnson-Laird, 1972). Mental models account for effects of meaning, and the ability to reason in unfamiliar premises (Byrne, 1992).

de Kleer and Brown (1983) describe mental models as qualitative simulations of a complex physical device made up of simpler components and mechanisms. The structure of a static system informs one about the states of components, and the behaviors of relationships. Simulation of components and component relations allows for the generation of inferences about system relationships. Schwartz and Black emphasize imagery in mental models, describing “de-pictive simulations” as representations that simulate system mechanisms, from which rules can be derived (1996a; 1996b).

de Kleer and Brown (1983) differentiate between simulation as a process and as an artifact, using the word “envisioning” to refer the simulation process and “causal model” to refer to the artifact of simulation. “Envisioning” allows one to determine the function given the structure and principles, and to determine the behavior for each component, given model characteristics. The “causal model” describes functioning and the model must be developed before it can be “run” to produce a certain effect. “Running” involves developing a causal model to produce a certain effect “Running” of a mental model occurs when autonomous objects change states, thus influencing other autonomous objects (Williams et al., 1983).

This line of research led to the following questions:

• How would qualitative cues about system components presented in images and text during computer-based scientific inquiry influence mental representation? Would mechanistic depiction of components lead to envisioning and running of models?

• How would qualitative cues, influencing mental representation, affect reasoning and learning? Would more animated representations advanced inquiry and learning?

**Program Design**

_Flood Predictor_ is an educational and research software program, created with Macromedia Director, which supports the investigation of causal relationships in the domain of elementary hydrology (Kuhn et al., 2000). Scientific reasoning activity is based upon Piagetian reasoning tasks (Inhelder and Piaget, 1958; Piaget, 1972), in which multiple factors contribute to creating an effect (i.e. a pendulum swing), and previous studies by Kuhn and Schauble (Kuhn, 1989; Schauble, 1990; Kuhn et al., 1992), in which students make inquiries and predictions, and revise theories about a multivariable system.

In _Flood Predictor_, participants are guided into deductive reasoning strategies while investigating causes of flooding. Anchoring instruction has been found to be effective in science education (Goldman et al., 1996). Applying Goal-based Scenario constructivist design principles (Schank et al., 1994), students are placed in the role of a builder working for a construction company, and assigned the job of determining how high to build stilts under houses near a group of lakes. Employees are informed that, in order to avoid flood damage and to minimize the cost of expenditure on unnecessary materials, they must determine which factors in the region will cause flooding and which will not.

Five factors are introduced as potentially causal in affecting flood level: Water Pollution (high vs. low), Water Temperature (hot vs. cold), Soil Depth (shallow vs. deep), Soil Type (clay vs. sand), Elevation (high vs. low). Three of these factors (Water Temperature, Soil Depth and Soil Type) are causal within the program scenario.

Table I summarizes the causal structure of the _Flood Predictor_ system, and outcomes of specific combinations. There is one interaction in the program, between Soil Depth and Soil Type. Water Pollution and Elevation are not causal within the problem space.

Discoveries can be made by calling up records of sites by creating unique combinations of features, predicting how high flooding will rise, and making conclusions about whether features matter, do not matter, or had not found out yet. Figure 1 is a screen shot of the interface for calling up and comparing records. After each instance of examining records, students are queried about how they know that certain features