Developing Cognitive Prerequisites to Support Inquiry Learning in a Computer Environment

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ABSTRACT

Present work describes an intervention, which improves students' inquiry learning skills by facilitating their understanding of multivaraible causality.

Keywords

Inquiry learning, knowledge acquisition, scientific reasoning, metacognition, mental models, goal-based scenarios

INTRODUCTION

Inquiry learning is an educational method, in which students engage in authentic scientific investigation activities. Typically, such activities involve exploring multivariable causal systems, with the goal of inferring causal relationships among the variables. The popularity of the method is reinforced by the advent of technology in schools. Through computer simulations, students can access complex biological, environmental and social systems, previously inaccessible to school labs. Yet, psychological research on scientific thinking warns educators that children and adolescents often experience difficulties with various stages of experimentation. They generate imprecise hypotheses, design inconclusive experiments, and tend to reject or misinterpret data that does not fit into their pre-existing theories (Kuhn, Zohar, Andersen & Garcia-Mila, 1995). Attempts to provide direct instruction in experimental strategies typically result in a very limited transfer of skills. Kuhn (in press) suggests that students' difficulties with scientific investigations extend beyond the level of performance, reaching into the meta-level. What is lacking is a clear understanding of task objectives, and metastrategic competence in selecting and monitoring performance-level strategies. Recent work, conducted by Kuhn and colleagues (Kuhn, Black, Keselman & Kaplan, 2001) suggests that many adolescents may also have deficient models of multivariable causality, in which the effects of individual variables are neither additive nor consistent. The present study is an attempt to strengthen students' scientific reasoning skills by improving their meta-level understanding of experimentation and refining their models of multivariable causality. Over the period of seven weeks, three groups of students engaged in a computer exercise, with the objective of identifying environmental features associated with earthquake risk. All students worked in rotating dyads, thus strengthening their mastery of strategies through externalized cognition. For the students in the control condition, their work was limited to engaging in the performance level exercise. Students in the practice condition received some support, aimed at improving their understanding of causality. Finally, students in the instructional condition received the most support. We hypothesized that by the end of the study, students from the instructional condition will show the greatest improvement in their scientific thinking skills, followed by the practice group students.

METHOD

The study followed pretest-intervention-posttest design. Participants in the study were seventy-four students from three six-grade science classes of a New York City public middle school. One class was assigned to each of the three study conditions. The main task in which students engaged repeatedly in the course of 5-7 sessions was a Macromedia Director computer program called Earthquake Forecaster. The task presented a multivariable environment characterized by 5 features (type of bedrock, snake activity, radon gas levels, water quality and s-wave rates) potentially instrumental in affecting the outcome – the risk of an earthquake. Each feature could assume one of the two possible levels (e.g., low or high), while the outcome assumed 4 levels (low, medium-low, medium-high and high). In a goal-based scenario, students were placed in the position of junior earthquake forecasters. They had to find out which of the five features played a role in causing earthquakes and learn to predict earthquake risk. Students investigated the environment by varying levels of the 5 features and observing resulting outcomes. In addition to participating in the main task exercise, students from the practice and instructional conditions also engaged in weekly paper-and-pencil prediction practice exercises. The exercises involved making and justifying risk predictions for Earthquake Forecaster instances presented by the researchers. The aim of the prediction exercise was to reinforce the understanding of the additive nature of multivariable causality. In addition to the main task and the prediction practice, students from the instructional condition also received weekly instruction in making predictions of flood risk, aimed at advancing their models of multivariable causality. In these sessions, the primary investigator modeled combining the effects of all causal features in order to derive the outcome. To equate time on task, students from the control and practice groups engaged in weekly discussions of scientific studies, relevant to middle school curriculum.

RESULTS AND DISCUSSION

After viewing each instance of the program, students had an opportunity to draw inferences about the features of the system. In analyzing the results, we relied on Kuhn's theory of knowledge acquisition (Kuhn et al., 1995). This theory suggests that students whose knowledge acquisition skills are weak have difficulty distinguishing between theory and evidence as the sources of knowledge, and using evidence to modify their theories. At this early point of the continuum, students are likely to state that something is true, because they "just know it." The experimental evidence is not implicated. At a somewhat more sophisticated level, students begin to appreciate the role of the evidence in the process of knowledge acquisition. Yet, they view a single experimental instance as providing sufficient information to draw conclusions about all the features of the system. The next step in knowledge acquisition skills involves making inferences based on comparisons (albeit uncontrolled) of instances. Finally, the most sophisticated level requires designing a controlled comparison between two instances, and subsequently drawing a correct inference about the feature under investigation.

As hypothesized for the present study, the gain in scientific reasoning skills was greatest in the instructional condition, followed by the practice condition. Yet, results of the study suggest that students from all three conditions derived benefit from participation. Repeated measures ANOVA yielded overall significant time effect for the number of unique instances students viewed within a program run, the proportion of evidence-based responses and the number of valid inferences about the causal status of the program features. This suggests that repeated engagement in self-directed investigations alone may lead to some improvement in students' scientific skills. This finding is consistent with previous research on scientific thinking (Kuhn, Zohar, Andersen & Garcia-Mila, 1995). Use of the evidence, however, was greater in the practice and instructional than in the control condition. For example, although students from all conditions showed pre- to posttest increase in the proportion of evidence-based responses, the improvement was greater in the practice and instructional conditions. Moreover, students from the instructional, but not from the practice and control conditions, demonstrated an improvement in the number of inferences, drawn on the basis of multiple records. This suggests that an intervention that drew the students' attention to the additive and consistent nature of individual effects in multivariable systems improved their understanding of the role of comparisons in experimentation. This improvement was maintained in a transfer task. Finally, as a result of their superior investigation strategies, students from the instructional group also showed a pre- to posttest improvement in their knowledge about the causal status of the features of the program.

Overall, this work supports the notion that both metacognitive understanding of task objectives and strategies as well as normative models of multivariable causality serve as prerequisites for developing scientific reasoning skills. Consequently, both need to be present in an effective intervention that aims to support students' inquiry learning. Future studies may focus on the interaction between metacognition and the understanding of causality, and on the process of development of normative causality models.

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