Learning to Evaluate Scientific Models

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Abstract: The construction and evaluation of scientific models, together with the iterative modification of these models in response to evidence, constitute paradigmatic scientific practices. If inquiry instruction is to engage students in authentic scientific reasoning, these practices need to become routine in the science curriculum. This paper reports on some of the difficulties middle-school students experience in a learning environment focused on model- and evidence-based reasoning and suggests a promising scaffold to address these difficulties.

Modeling in Science

In recent years, philosophers of science have emphasized that much scientific activity is focused on the development, testing, evaluation, and refinement of scientific models (e.g., Giere, 2004). Accordingly, an increasing number of science educators and learning scientists are investigating modeling in science classrooms. Learning to use models presents students with considerable challenges. Successful use of models requires the ability to proficiently deploy a variety of cognitive strategies, including (to list just a few) (a) constructing models on the basis of evidence, (b) revising models in the light of additional evidence, (c) convincingly justifying models, (d) evaluating alternative models using multiple sources of (sometimes conflicting) evidence, and (e) generating explanations and predictions from alternative models.

Until recently, most research on scientific reasoning focused on very simple reasoning tasks of questionable relevance to real scientific reasoning (Chinn & Malhotra, 2002). These tasks were often decontextualized and inauthentic. Model-based reasoning is one promising avenue to promote authentic reasoning in classrooms (Duschl, Schweingruber, & Shouse, 2007).

An Overview of the Study

We carried out a yearlong project investigating middle-school life-science students learning model-based reasoning. In this paper we focus on a particularly productive scaffold, developed to promote students' model-based reasoning. We will explain how this tool was used by teachers and students to overcome many of the obstacles they faced in the effective use of scientific models for learning.

The larger research project involved close collaboration with teachers in the development of instruction centered on *reasoning seminars*--small-group and whole-class discussions in which students engage in collaborative argumentation, using evidence to construct, revise, compare, and evaluate explanatory models. We identified a set of target reasoning strategies centered on scientific models, data, evidence, and justifications. We traced the day-to-day use and development of these strategies over an eight-month period in classes taught by 7 teachers; 12 of these teachers' 33 classes were video recorded most or all days over the eight months. We use detailed data gathered over an extended period of time to generate a rich picture of day-to-day learning processes. Other initial findings are elaborated in Chinn, Duschl, Duncan, Buckland, & Pluta (this volume).

Although students' model-based reasoning improved substantially over the course of the year, many students found aspects of the curriculum particularly challenging. One widespread difficulty was the effective use of reasons and evidence. Students typically found it difficult to make judgments about the relative strength of evidence, and rather tended to treat all evidence as equally strong. They also had difficulty understanding the need to provide justifications that were more elaborated than just mentioning the evidence that provided support.

Evidence-Model Diagrams

The pervasiveness of these difficulties encouraged us to develop a new scaffold focused on helping students understand connections between evidence and models. The scaffold, dubbed the "Evidence-Model (EM) Diagram," is a graphical representation designed to facilitate the effective coordination of multiple pieces of evidence in the evaluation of one or more models (cf. Thagard, 1992). The scaffold directs students to draw different kinds of arrows between evidence and models to denote different kinds of inferential links, including 'supports,' 'strongly supports,' 'contradicts,' 'strongly contradicts,' and 'is irrelevant to.' Students then provide reasons to justify their choice of arrows. We developed several increasingly complex versions of the EM Diagram tool. The initial, introductory format consists of a single piece of evidence and a single model, while a more complex version includes several pieces of evidence and a single model. A more sophisticated format sets multiple pieces of evidence against two competing models. The EM Diagram scaffold provides a perspicuous means of representing the complex sets of model-evidence relations involved in the evidence-based evaluation of a scientific model. On completion, the scaffold constitutes a concise, justified summary of an episode of a student's reasoning, one that appears to positively impact student learning in several different ways.

Findings

We found that the EM Diagram scaffold enhanced students' understanding of how to coordinate models with evidence. In addition, it stimulated argumentative discussion far more readily than the other representations that we employed. The need to decide which kind of arrow to draw (e.g., 'supports', 'strongly supports', etc.) and the need to explain and draw conclusions from the completed set of arrow links appeared to elicit far richer and more detailed model-based argumentation than did most other tools we investigated.

The example below shows one version of the EM Diagram. This student first drew conclusions from studies and then linked this evidence to two models of photosynthesis (neither of which was fully satisfactory). This student's justifications are shown on the right. Compared with earlier justifications, these exhibit more explicit linkages between characteristics of the model and the details present in the evidence–a key component of effective model-based reasoning, and integral to the reasoning strategies described above.

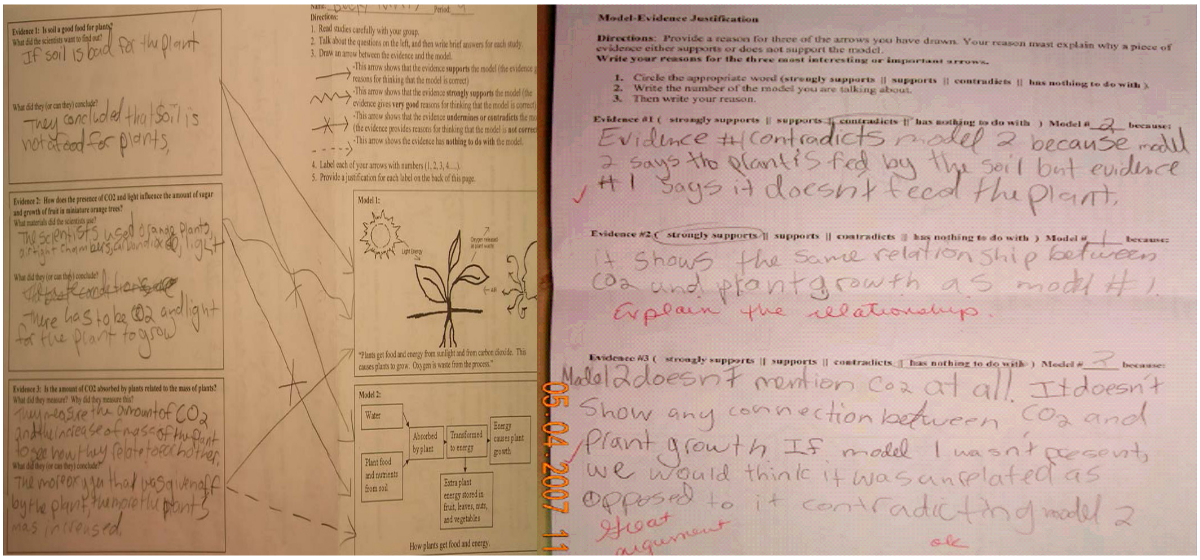

Figure 1. One student's use of the Evidence-Model Diagram tool.

The EM Diagram makes the interrelations among models, evidence, and justifications more intuitive. By representing model-evidence relations in a clear graphical format, it exposes the important differences between evidence and the justification that explains why the evidence supports the model. The scaffold also led students to an appreciation of the differing relative strength of multiple pieces of evidence, as it directed them to assess each piece of evidence on its own terms, before combining these judgments in an overall decision.

Conclusion

We have found the Evidence-Model Connection diagrams to be a very useful scaffold for promoting higher level modeling and reasoning about evidence. Our ongoing research into the impact of this scaffold involves the examination of video footage of the classroom discourse before, during, and after its introduction. The goal is to investigate growth in reasoning using the scaffold over time and to examine whether its effects differ in interesting ways between classes and schools.

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