A Microgenetic Classroom Study of Learning to Reason Scientifically through Modeling and Argumentation

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Abstract: We report on a large study of how U.S. middle-school students learned to reason scientifically in a science curriculum centered around models and argumentation. We discuss the design of our curriculum, the method of the study, and present selected results related to overall curriculum effects and to methods of promoting growth in students' reasoning.

Introduction

In this paper, we report results from a yearlong microgenetic, quasi-experimental study of middle-school life-science students learning to reason scientifically. The students participated in an inquiry curriculum in which they regularly engaged in constructive argumentation aimed at constructing, revising, and evaluating scientific models on the basis of evidence. In the following, we briefly describe (a) the design of our model-based inquiry curriculum, (b) the method, and (c) selected findings about students' growth in reasoning.

Learning to Reason Scientifically through Modeling and Argumentation

Despite the importance of learning to reason well, many or most adolescents and adults are not proficient in important aspects of scientific reasoning (Zimmerman, 2000). To promote better scientific reasoning, we have focused on reasoning about scientific models because the construction and evaluation of scientific models is a core scientific practice (e.g., Longino, 2002). Model-driven practices have allowed us to consider expanded notions of scientific inquiry that center on the dialogic discourse and epistemic activities of coordinating explanatory models with evidence (Duschl, Schweingruber, & Shouse, 2007).

In accordance with these aims, we worked with teachers to develop instructional schemes centered around *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. In a typical instructional module, students construct initial models of a process (such as how things get in and out of cells). Students then gather evidence themselves, and they read about other evidence reported by scientists. Through dialogic argumentation in a variety of small-group and whole-class contexts, they consider alternative models in the light of the available evidence, adopt the model that is most promising, and make further changes to that model as they encounter additional evidence. Teachers and students explicitly set goals for reasoning (e.g., a goal for one module might be to learn to explain the same evidence from the perspective of two different models) and then evaluate whether these goals are being met.

Method

We carried out a yearlong quasi-experiment in twelve school districts in a state on the East Coast of the U.S. Seven teachers and 724 middle-school students (most aged 12-13) in 5 districts participated in the modeling-based curriculum outlined above. Half of these classes were video recorded throughout the year. Another 23 teachers and 1,961 students in 7 districts participated in a control group matched on SES, district size, and performance on state assessments. Counterbalanced pretests and posttests assessed inquiry abilities within a variety of problems, including performance assessments embedded within a two-day inquiry lesson.

The study was also a classroom microgenetic study exhibiting two key features (cf. Siegler & Crowley, 1991): (a) Learners were observed daily over more than 8 months; (b) Measures of individual learners' strategy use were relatively dense so that we could detect knowledge changes as they occurred and then work backwards to understand instructional events that facilitated these changes. Microgenetic studies require measures that can be used repeatedly--a challenge in a yearlong study. A modeling-based curriculum is ideal for developing such measures because modeling entails the use of many types of inscriptions besides simple prose writing.

Results

Growth in Reasoning

Results from the written posttest have shown that in comparison to students in control classes, students in modeling classes made substantially greater advances in their ability to effectively coordinate models and evidence. For example, on one posttest problem, students evaluated two alternative models of delayed onset muscle pain on the basis of five pieces of real scientific evidence. Typical responses by control students made no mention of evidence (e.g., *The muscle fiber model makes more sense to me*) or mentioned evidence only generically (e.g., *The lactic acid model fits the studies better*). Students in modeling classes were better at articulating model-evidence connections in detail. Many also noted that it was necessary to modify the muscle fibers model (which did not posit cell swelling) to account for a study reporting swelling in painful muscles.

Substantial improvement in the sophistication and coherence of students' use and understanding of epistemic norms was observed over the course of the year in the modeling classrooms. One important shift was from an initial preference for communicative and aesthetic criteria for evaluating scientific models to a preference for criteria of empirical and representational accuracy. For example, an early list of criteria for good models generated by one class made no mention of evidential criteria. Their criteria included: (1) Step by step sequence, (2) Simple, (3) Has to explain, (4) Self-explanatory, (5) No perfect model, must redesign for each age group, (6) Have key labeling, (7) Have words and pictures, (8) Have more than one possible model, (9) Add color. The shift toward including evidential criteria occurred in all classes, but the change occurred slowly and unevenly within and across different classes.

Effective Instructional Practices

Our results provide support for a broad range of instructional practices. Four of these are described below (see Pluta, Buckland, et al. , this volume, on another scaffold that proved to be highly effective).

1. *Public criteria for good models and good reasons.* Teachers and classes developed one set of publicly posted criteria for good models and a second set of criteria for good reasons or justifications. Students and the teacher then worked throughout the year to refine and improve their criteria. These criteria were an effective focal point for many other activities and were regularly referred to by teachers and students.
2. *Ranking models or reasons using criteria.* A task that stimulated extensive argumentation about criteria and their application was ranking three or four alternative models according to model criteria, or ranking three or four reasons according to reason criteria. These ranking tasks led students to reflect in detail on how criteria applied to particular cases and whether the class's criteria were adequate to distinguish not only between good and bad models (or reasons), but also--and critically--between good and very good models (or reasons).
3. *Deliberate introduction of poor models and poor reasoning.* To deepen students' appreciation for certain epistemic criteria, teachers found it productive to deliberately present poor models or poor reasons for students' consideration. For example, students found it easier to understand why elaborated reasons were valuable when teachers made claims such as "I think that a pickles-only diet is good because scientists did an experiment" or "It's good because it said so in a book." Presented with such examples, many students grasped that elaborated reasons are essential because they are needed to allow open and public criticism of ideas, a process of critical argumentation that is central to the scientific enterprise (Longino, 2002).
4. *"Thought bubbles" linking reasons for model revisions.* To encourage greater sophistication in linking evidence to models, we developed the technique of having students write evidence-based reasons for model revisions in "thought bubbles" linked to the revision. This scaffold helped students understand that evidence does not merely support or contradict models as a whole; evidence can often be taken to support or contradict particular parts of models. Students thus learned to link evidence to models more precisely.

Conclusions

The initial results of this study support the effectiveness of a reasoning curriculum centered around modeling and argumentation. Although analyses of microgenetic data are just beginning, we have uncovered shifts in epistemic criteria spanning a year of intensive engagement with modeling and argumentation activities. And we have begun identifying instructional techniques that appear to strongly advance students' ability to articulate and apply epistemic criteria for linking models to evidence.

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