Strategy Levels for Guiding Discussion to Promote Explanatory Model Construction in Circuit Electricity

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Abstract: A framework for describing and tracking the whole-class discussion-based teaching strategies used by a teacher to support students' construction and development of explanatory models for concepts in circuit electricity is described. A new type of diagram developed to portray teacher-student discourse patterns facilitated the identification of two distinct types, or levels, of teaching strategies: 1) those that support *dialogical* or conversational elements of classroom interaction; and 2) those that support cognitive *model construction* processes. The latter include the higher-level goals of promoting a cycle of Observation, model Generation, model Evaluation, and model Modification. While previous studies have focused primarily on the dialogical strategies that are essential for fostering communication as an enabling condition, the cognitive strategies identified herein are aimed at fostering conceptual model construction.

Keywords: Teaching strategies, model-based learning, whole-class discussion, high school physics.
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INTRODUCTION

As a long-term goal, we have been engaged in identifying *cognitive strategies for fostering model construction* that could complement known *dialogical strategies for encouraging conversations in large group discussions*. This paper introduces a distinction between cognitive and dialogical strategies using examples from high school electricity teaching and describes a diagramming system for tracking both kinds of strategies.

THEORETICAL FRAMEWORK

Discussion-Based Teaching

There is considerable agreement that classroom discussions, both student-to-student and between students and teacher, can serve as important means for facilitating the construction of scientific knowledge [1]. In particular, the idea that student reasoning abilities can be supported through whole-class discursive interactions with others draws on the early work of Vygotsky [2]. Many contemporary researchers [3,4] also believe that discussion plays an important part in conceptual change and that teaching with a focus on discussion can improve scientific reasoning ability.

Model-Based Learning

In the context of this research, a model is considered to be a simplified representation of a system, which concentrates attention on specific aspects of the system [5]. An *explanatory* model for a system is a hypothesized, theoretical, qualitative mental model (such as molecules, waves, and fields) that provides a (usually causal) description of a hidden, non-observable mechanism that explains how the system works. These can enable aspects of the system, i.e., objects, events, or ideas that are either complex, abstract, or on a different scale to that which is normally perceived, to be rendered more readily visible [6] and are the focus here. Model-centered or model-based learning is grounded in the theory that humans construct "mental models," internal cognitive representations that support reasoning and understanding by simulating the behavior of systems in the real world [7]. In model-based learning, it is assumed that learners construct explanatory mental models of phenomena in response to particular learning tasks, by integrating pieces of information about structure, function/behavior, and causal mechanisms. Learners then use and continuously re-evaluate their models, discarding or revising them as needed.

A Model-Based Approach to Learning about Electricity

In an approach to learning electricity via explanatory models, students are encouraged to focus first on the causes behind what is happening in the wires. The mathematical quantification of voltage, current, etc., is usually left until later in instruction, serving to verify and support the students' working mental models. Clement and Steinberg [8] discuss an approach to teaching complex models of electricity based on a *model construction cycle* of Generation, Evaluation, and Modification (referred to as a GEM cycle). Through this process of *model evolution*, or incremental growth in sophistication of a model, students are led to reassess and revise their model many times. Their learning approach is centered around Steinberg's [9] CASTLE (Capacitor Aided System for Teaching and Learning Electricity) curriculum, which utilizes the introduction of large, non-polar capacitors into basic electric circuits as a way to focus students' attention on the transient states of potential differences that exist throughout the circuit. By using the analogy of voltage as a type of "pressure" that exists in the "compressible electric fluid" of a circuit, students are encouraged to generate images of dynamic pressure changes occurring throughout the circuit as these capacitors go through their charging and discharging cycles.

Studies [10, 11] found that students in these model-based learning classes recorded significantly greater gains in electric circuit problem solving and reasoning abilities than their counterparts who learned the concepts of electricity through more traditional, lecture and equation-based means. In this paper, we describe a method of tracking specific types and levels of whole-class-discussion-based teaching strategies that one teacher used to foster such students gains.

STUDY CONTEXT & SETTING

This grounded theory study was conducted with a ninth grade science class that was studying an instructional unit on the fundamental concepts of circuit electricity. The 18 students (9 male and 9 female) at a small private suburban high school in New England spent approximately six weeks working with the CASTLE curriculum on activities of incremental model building. Their male teacher was a 30-year veteran of high school physics and was very familiar with model-based instruction. The structure of the classroom sessions had students working in pairs, alternating between assembling and testing circuit experiments, completing readings and responses in their student workbooks, and participating in full class discussions moderated by the teacher.

DATA COLLECTION & ANALYSIS

This work builds on a research methodology and analytical techniques [12] in which videotaped segments of whole-class discussions were used in the identification of model-based teaching strategies. Several five- to six-minute segments, in which the teacher and students appeared to be engaged in the co-construction of explanatory models, were selected for analysis. Once detailed transcripts of these segments were prepared, interpretive descriptions of the teacher's strategies or moves were generated. A diagrammatic representation of the teacher-student discourse patterns was developed in an attempt to: a) present the spoken contributions of teachers and students, b) describe the functions of these utterances, c) categorize the levels of various teaching strategies, d) track the evolution of the explanatory models as revealed through the discourse Analysis utilized a constant comparative method leading to open coding, followed by refinement of categories in joint coding with the second author.

RESULTS

The following is a description of the diagrams that resulted from the analysis outlined above. Because it typically requires a diagram 2-4 ft. wide to portray 5-6 minutes of model-building activity, an abridged diagram of 15 seconds of discussion is presented here to illustrate the technique. Figure 1 shows time running from left to right. The horizontal strip across the middle of the diagram contains icons (generalized images) of the evolving model. These are based on the sequentially numbered student and teacher statements, above and below the icons. The icons represent our hypotheses about the students' collective model, as revealed through their discourse, at given points in the discussion. In Fig. 1, the first icon portrays a slight compass deflection and an unlit bulb, observed in earlier class experiments. (A circuit containing too many resistors for a bulb to light still caused a compass to deflect). The second icon portrays one student's hypothesis: resistors are absorbers of charge, leaving enough charge in the wires to deflect a compass but not enough to light the bulb.

One layer further away from the icon strip, in each direction, are brief descriptions of the function of each student and teacher contribution. For the teacher, instructional strategies are separated into two distinct categories or levels: 1) those that support the *dialogical*, or conversational, elements of classroom interaction that are essential to effective two-way communication and sharing of ideas, 2) those that appear directly to influence the cognitive *model construction* processes.

Dialogical teacher strategies are generally observed to be conversational in nature; occur within a very short timeframe; support dialogical interaction; encourage increased student participation and ownership in the discussion; and foster a classroom culture that promotes and encourages student input, values opinions, and considers alternative conceptions and viewpoints. Previous studies [13,14] have made valuable contributions to the identification and description of these types of teacher strategies. Examples identified in this teacher's repertoire that are *not* portrayed in the abridged diagram include:

* Repeating student answers for emphasis
* Praising students for contributing
* Allowing scientifically incorrect statements
* Eliciting student voting
* Using diagrams to clarify
* Paraphrasing student responses for emphasis/clarity

Model construction teacher moves can generally be observed to utilize cognitive strategies for fostering model construction and evolution through questions and comments that focus on students' pre-conceptions, patterns in the data, and the processes of reasoning about the scientific concepts at hand. Generally, these moves appeared to influence the direction of discussion for longer periods than the conversational moves described above. Examples in addition to those shown in Fig. 1 include:

* Initiating Retroactive Discrepant Events – asking students to recall the results of a previous experiment or demonstration to generate cognitive dissonance
* Helping students focus on patterns in the data
* Asking students to differentiate or integrate aspects of the model
* Requesting that experimental observations be explained
* Initiating Discrepant Thought Experiments – asking students to run a mental model and to make predictions from it to compare with experimental data

The levels on the extreme top and bottom of the diagram outline the progression of the whole-class-discussion sequence through the various phases of a higher-order strategy for driving the co-construction of models. A brief indication of two of the phases is shown. The complete cycle is Observation, Generation, Evaluation, and Modification, with multiple instances of each phase occurring within the conversation excerpted here. Previous studies [15-16] have contributed precursory diagramming techniques and have identified the last three phases of this cycle as they occurred during teacher- student co-construction of explanatory models in science classes, and during model construction activities of expert scientists [17]. The model construction cycle, as previously described, was: Generation (G), Evaluation (E), and Modification (M). Because of the nature of the CASTLE curriculum with its frequent and integrated use of student experiments and teacher demonstrations, recent studies [12] added an additional *Observation* (O) phase to the process, resulting in the OGEM cycle discussed here.

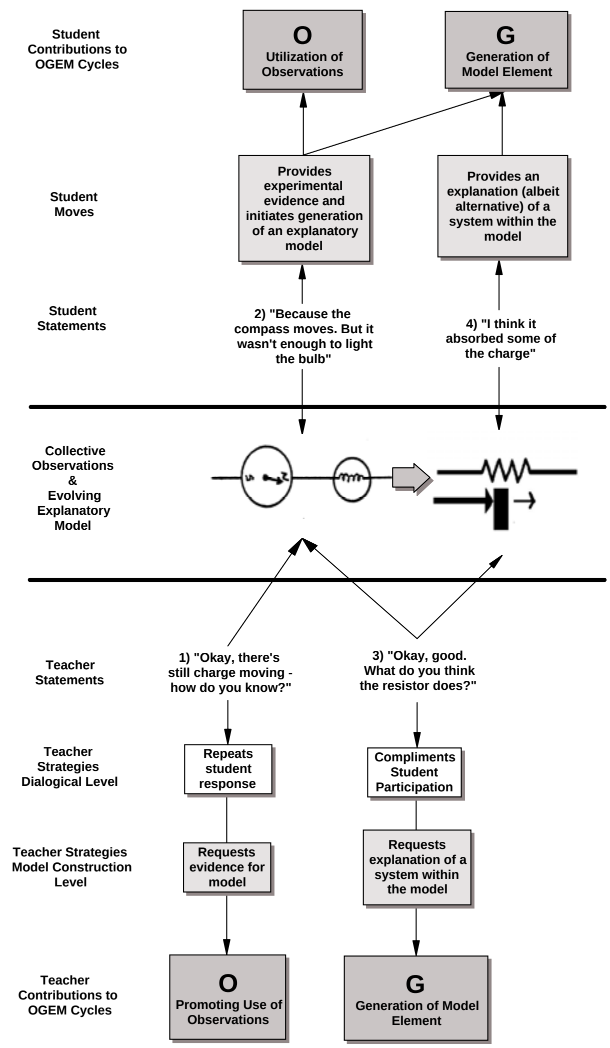

FIGURE 1. Model Construction through Discussion

The teacher strategies portrayed in the second-to-bottom level of the diagram are shown to contribute to higher-order goals shown in the bottom level. The two strategies shown here contribute to the higher-order goals *promoting the use of observations* (O) and *generating model elements* (G). Other examples of teaching strategies, not included in the above diagram: asking a discrepant question to promote the evaluation of a misconception (*promotes model evaluation*, E), and asking for alternative descriptions or explanations (*promotes model modification*, M).

The diagram allows us to portray teacher-student co-construction in detail. It was noted that this teacher frequently implemented dialogical and model construction moves together, in single utterances, in the service of keeping his students engaged in the conversation yet continuously constructing their models. The diagram also allows us to tie the hypothesized strategies to transcript observations as a way to constrain our theorizing about the influence of these strategies on students' construction of mental models. We see this work as complementing other important work [18, 19] on meta-cognitive strategies and the tradeoffs between content and process goals. In our next phase of work, we plan to triangulate from teacher interviews about these video segments to enhance the validity of our diagrammatic models of teaching strategies.

CONCLUSION

This paper has outlined the development of a methodology for describing and tracking whole-class discussion-based teaching strategies. Through a new diagramming technique, two distinct levels of teacher moves were posited: *dialogical* teacher strategies that foster students' active participation in science discussions, and cognitively-focused *model construction* strategies that the teacher used to support students' construction of explanatory mental models for circuit electricity concepts. Of the various teaching strategies found to exist at the model construction level, it is hypothesized that each can also contribute to the higher-order goals of promoting a cycle of Observation, model Generation, model Evaluation, and model Modification.

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