FACILITATING EFFECTIVE WHOLE-CLASS DISCUSSIONS: STRATEGIES FOR SCIENCE EDUCATORS

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ABSTRACT

Many of the topics that students encounter in their study of science require them to navigate abstract and conceptually challenging ideas. Based on research of the discussion-leading practices of a group of experienced high school physics educators teaching the concept of circuit electricity, this paper presents a sampling of conversational strategies that are believed to go beyond previously identified *dialogical* tactics and support student reasoning at a higher *cognitive model construction* level. The paper utilizes examples from classroom discussion transcripts to describe the roles that these teaching strategies are hypothesized to play in students' construction, evaluation, and revision of explanatory models for abstract scientific concepts. The article describes a seven-step process that introduces pre-service *secondary science* teachers to effective techniques for leading discussions.

Introduction

Whether it be elementary school or graduate school, many of the topics that students encounter in their study of science require them to navigate abstract and conceptually challenging ideas (Keeley, Eberle, & Farrin, 2005; Koba & Mitchell, 2011). This may be because the phenomena involved occur on scales that are either too large or too small to be readily observed (e.g., galaxies and atoms), occur at rates that are either too fast or too slow to be witnessed (e.g., light travel and continental drift), or occur in hidden situations (e.g., electric circuits and the human circulatory system). Science educators at all levels are charged with finding ways to make these conceptually challenging ideas accessible to students in a manner that facilitates the development of cogent and fruitful understanding.

Based largely on the work of Vygotsky (1962), educational research has begun to understand the impact of classroom discussions as a means for facilitating the construction of scientific knowledge. Research by Hammer (1995), Roth (1996), van Zee and Minstrell (1997), Hogan and Pressley (1997), and Chin (2007) has identified some key elements for leading whole-class discussions and the impact of particular strategies on student engagement. These include participating mainly as a facilitator in the discussion, restating or summarizing student statements, asking for elaboration and clarification, redirecting questions back to students rather than providing answers, focusing attention on conflicts and differences of opinion, inviting responses to other students' statements, and choosing to not directly challenge "incorrect" statements.

The work of these researchers has yielded important findings in the facilitation of whole-class discussions, largely resulting in the generation of lists of conversational techniques of what I refer to as a *dialogical* nature—strategies intended to foster the clear and open communication and sharing of student ideas through class discussion. These research findings are valuable in that they provide understandings of how science instruction has evolved from a traditional teacher-centred approach to one that is focused on the students as active participants in their own learning.

What these studies have generally *not* investigated, however, are the strategies that effective educators use during whole-class discussions that may support students' cognitive reasoning about scientific conceptions. It is my belief that whole-class discussion-based teaching strategies also exist at another, *cognitive model construction* level, and that these strategies can foster students' construction and refinement of explanatory models to help them visualize, comprehend, and reason about scientific phenomena. Collins and Gentner (1987), Gilbert and Boulter (1998), Vosniadou (2002), Gobert and Buckley (2000), and Windschitl, Thompson, and Braaten (2008) agree that engaging students in the processes of developing, evaluating, and reforming explanatory models can play a significant role in promoting their abilities to reason cognitively about various scientific concepts.

Before further discussing conversational teaching strategies at this second, more cognitively engaging level, it is important to explore the role that modelling plays in the learning process. The term *model* has many meanings; however, in the context of this article, a model is considered to be a simplified representation of a system or phenomenon that make its central features explicit and visible and which can be used to generate explanations and predictions (Harrison & Treagust, 2000).

Explanatory models are the descriptions or representations (verbal, symbolic, pictorial, graphical, numeric, etc.) that students develop to support and express their understandings of particular concepts or phenomena (Clement, 2008; Hafner & Stewart, 1995; Williams, 2011). Students' development of explanatory models is believed to be supported by their construction of *mental models*, described as internal cognitive representations that support reasoning and understanding by simulating the behaviour of systems in the real world (Johnson-Laird, 1983; Schwartz & Black, 1996). Science instruction that is referred to as *model-based* utilizes curricula, learning tasks, and teaching strategies that have been designed to foster students' construction, evaluation, and revision of explanatory models for the purposes of making sense of abstract and challenging concepts and phenomena.

In my current research, I seek to identify and describe the specific types of discussion-based strategies that exemplary science teachers utilize in fostering students' construction of explanatory models. The findings that I share in this article are based on a recent study in which I investigated the cognitively targeted conversational tactics employed by a group of high school physics teachers to support their students' development of explanatory models for the concepts of charge, energy, current, voltage, and resistance in electric circuits. My aim was to determine whether the strategies that were used existed on multiple levels and if so, what the relationships between such levels might be.

Research Methodology

Since my intent was to investigate teachers who utilized whole-class discussions to promote students' participation in model construction activities, I started by identifying high school physics classes that were learning about circuit electricity through a model-based curriculum. This curriculum, known as CASTLE (Capacitor Aided System for Teaching and Learning Electricity), centres on a conceptual model of charge as a compressible fluid, experiencing differing degrees of pressure (voltage) and resistance as it flows through varying components of a circuit. This is in distinct contrast to traditional curricula that treat electricity as the flow of electrons in wires whose quantitative behaviours are dictated by the Ohm's Law equation $V = IR$.

Over the course of the 6–8 weeks of electricity study, approximately 30 hours of classroom activity was videotaped and later transcribed. The primary use of this data was the identification and description of specific discussion-based strategies that the physics teachers used in fostering students' cognitive model-building processes. Therefore, the focus of this data collection process was on capturing segments in which the teachers and their students appeared to be engaged in the co-construction of explanatory models of electricity through whole-class discussions. A grounded theory qualitative research approach (Strauss & Corbin, 1998) was employed for this part of the study. In particular, the constant comparison method (Glaser & Strauss, 1967) was utilized in an effort to develop plausible interpretations of the teachers' conversational strategies.

Teachers' spoken statements on the transcripts were coded into the two levels described previously: Level 1—*dialogical* strategies that support students' active participation in scientific conversation and Level 2—*cognitive model construction* strategies that foster students' engagement in the development of explanatory models to support their understanding of scientific concepts. *Dialogical* teacher strategies were generally observed to be conversational in nature, occur within a very short time frame, support dialogical interaction, encourage increased student participation and ownership in the discussion, foster a classroom culture that promotes and encourages student input, value opinions, and consider alternative conceptions and viewpoints. *Cognitive model construction* strategies, on the other hand, were generally observed to utilize cognitive strategies for fostering model construction and evolution through questions and comments that focus on students' preconceptions, patterns in the data, and the processes of reasoning about the scientific concepts at hand. Generally, these strategies appeared to influence the direction of discussion for longer periods than the dialogical strategies described above.

Strategies at the *cognitive model construction* level were then further coded as contributing to one of four phases at yet a third level—the *model construction cycle.* The four phases of this cycle are experimental Observation, model Generation, model Evaluation, and model Modification that appeared to direct the specific conversational teaching strategies at Level 2. Based on these phases, I refer to the model construction cycle as an OGEM cycle. The coding process I used to determine which phase each of the teachers' statements were believed to contribute to utilized the following criteria:

Observation **(O):** The statement makes reference to observations made or outcomes noted either in a previous classroom experiment or demonstration, an everyday occurrence, a television or Internet video, or other source. This may be done for the purpose of bringing the attention or memory of the participants to the phenomenon being discussed. Examples of key phrases that help identify observation strategies: Did you see..., What did you notice..., Tell us about your observations..., What was detected..., etc.

Generation **(G):** The statement initiates or introduces a theory, model, conception, conjecture, or opinion. This may be done in an attempt to explain, convince, persuade, clarify, simplify, or describe one's thinking or understanding to others. This can be done in either a declarative or interrogative manner. Examples of key phrases that help identify model generation strategies: What ideas do you have about..., What do you think is happening..., What explanation can you think of for..., I think that maybe what's going on is..., etc.

Evaluation **(E):** The statement refers to a theory, model, conception, or explanation that has previously been or is currently under discussion. The purpose of the statement is to respond to, consider, evaluate, judge, refute, criticize, support, or endorse a particular explanatory model. Examples of phrases that help identify model evaluation strategies: Do you agree with..., That makes sense, I also believe that..., Are you sure you can have..., Do you think that is the way..., etc.

Modification **(M):** The statement offers a suggested change, adjustment, or modification to a theory, explanation or model that is under evaluation. This may involve only a minor alteration, variation or addition or could introduce a completely revised model with little resemblance to the original. Examples of phrases that help identify model modification strategies: Does anyone see it a different way..., Would anyone suggest changing..., Maybe if we explained it like this..., Could it be more along the lines of..., etc.

As a secondary source of data, reflective interviews were conducted with the teachers in an attempt to juxtapose my hypotheses about the model construction processes I was observing with their own beliefs about what was happening in their classes. Through a process of video and transcription review, I was also able to acquire feedback from the educators on the intentions and perceived effectiveness of their selected conversational strategies and share with them my theories about multiple strategy levels.

Sample Transcript Analysis

In an attempt to portray the nature and products of the investigative process, I am including here an example of my analysis of the transcript of a 5-minute whole-class discussion episode from the class of one of the teachers. Just before the whole-class discussion that took place in this episode, the students conducted an investigation from the CASTLE curriculum in which they started with a simple circuit containing one light bulb in series with a battery pack. A compass was placed under the wires of the circuit as an indicator of charge movement in the wires. The students then made adjustments to the circuit by adding a second and eventually a third bulb in series with the first and were asked to take note of the subsequent bulb brightnesses and compass needle deflections that occurred as a result of these changes. This exploration is designed to provide the students with the necessary data (brighter vs. dimmer bulb brightness, increased vs. decreased needle deflection) they require to engage in the construction of explanatory models for the effects of light bulbs on the behaviour of electric charge in circuits.

The transcript of the whole-class discussion segment follows (T indicates the teacher and S refers to students):

T: In what way do you think bulbs influence charge in a circuit?

S1: The bulbs, they take up some electricity from that part of the circuit so it leaves less for the next filaments.

T: Take up electricity. Anybody have another idea?

S4: We just thought that every time we did it [added more bulbs], it [charge] would just become slower and slower, so by passing through more bulbs, it probably just takes a longer time.

T: Longer time, okay. So it takes a longer time because?

S3: I would say that since the wires are so thin, then that way the charge flows through but when there's a filament, some of the charge gets lost in the bulb so it goes slower and takes longer.

T: So where does it go in the bulb? What happens to it when it gets to the bulb?

S2: It's getting used.

S1: It goes up to the filament and then goes back down so it's still connecting.

T: It's still connecting.

S5: Electricity is infinite.

S6: It's not infinite. It's a circuit!

S2: It's being used up.

S7: It gets more charge from the battery and goes around again.

S6: If it was infinite then we wouldn't be having gas [energy] problems.

T: Okay, so do you think the charge gets changed?

S4: No.

S2: Probably.

S3: I think it slows down.

S6: It uses up energy.

S1: It probably lowers.

T: So you think it's less?

S3: Yeah, it gets slower.

S4: I think it slows down much more because it has to light more stuff.

S1: Like, as it gets to the end of the circuit there's slower charge.

T: Okay, so a couple of people have said it slows down. So that's why the compass doesn't move as far?

S7: Do we know if the compass measures speed or charge? We don't know that yet.

T: Oh, well so far it measures charge flow rate, so the charge flow rate is different with one bulb and three bulbs do you think?

While it is virtually impossible to have every single student in the class participate in all classroom discussions, this teacher does manage to support seven of the nineteen in making contributions. What is perhaps initially most apparent about this episode is the teacher's ability to involve his students in extended periods of discussion with minimal participation on his part. What may not be apparent, however, is the work that the teacher is doing at the *cognitive model construction* and *model construction cycle* Levels 2 and 3.

He begins the discussion with a generative question *requesting the initiation of model construction (Strategy 1)* of the effects of light bulbs on charge movement in electric circuits. **"In what way do you think bulbs influence charge in a circuit?"** This is done to engage the students in the *model generation* process and begin brainstorming ideas about what might be going on inside the wires as bulbs are added to the circuit. When the first student response suggests the commonly misconceived explanatory model of light bulbs taking up or consuming some of the electricity, the teacher is careful not to evaluate the reply as being incorrect. Instead, the teacher utilizes the *dialogical* strategy of paraphrasing the student's response to honour it and make sure all other students in the class heard it, and then opens the floor to other explanatory models by using a different iteration of the *cognitive model construction* strategy of *requesting the initiation of model construction (1).* **"Take up electricity. Anybody have another idea?"**

Although one student suggests an explanatory model of reduced charge flow that partially aligns with the scientifically accepted model, it is clear that the notion of charge being used up, lost, or consumed in the light bulbs is still very much on the minds of many others. Exercising patience and restraint, the teacher elects to facilitate continued discussion rather than taking it over and allows the students to express their opinions, all the while paraphrasing key points and *requesting explanations to clarify the proposed models (Strategy 2).* **"So it takes a longer time because...?"** and **"So where does it [charge] go in the bulb?"**

After fostering the generation of four separate explanatory models for the condition of the electric charge (consumed by bulb, passing through filament, infinite, replenished by battery), the teacher makes a simple statement, which considers the general nature of all of the suggested models and *provides a summary of model elements contributed (Strategy 3)* stating**, "Okay, so do you think that the charge gets changed?"** This appears to set the students off on a spree of evaluation of the existing models and the generation of some additional ones.

After hearing a variety of student suggestions, the teacher selects to focus attention on one student's statement by paraphrasing it into a clarifying question, **"So you think it's less?"** This serves as a combined *dialogical* strategy, keeping the conversation moving, and a *cognitive model construction* strategy, *requesting evidence to support a model (Strategy 4)* of reduced charge flow. This encourages students to begin evaluating the model, drawing on their experimental observations for support.

The teacher then groups together and paraphrases the student responses that are concurrent with the target model of reduced charge flow rate that he is aiming for. Next he employs the strategy of *requesting students* *generate a model element based on evidence (Strategy 5)* in hopes that the students will continue to reason toward the target model, based on what they saw the light bulbs and compass needles do. **"Okay, so a couple of people have said it [charge flow] slows down. So that's why the compass [needle] doesn't move as far?"**

The segment ends with a question by a student concerning precisely what a compass needle's deflection indicates about charge movement in the wires it is placed nearby. The teacher first addresses the issue by *providing distinction between two elements of the model (Strategy 6)* regarding what is measured and then turns the discussion back over to the students by *requesting patterns in the observations (Strategy 7)* by asking whether charge flow rate is different with varying numbers of bulbs in the circuit. **"Oh well, so far [in our model] it measures charge flow rate, so the charge flow rate is different with one bulb and three bulbs, do you think?"** This serves to re-focus the discussion on the processes of generating and evaluating explanatory models for charge movement in bulbs and wires.

Findings

The analysis provided above represents a single 5-minute classroom discussion episode in which the teacher utilized seven different *cognitive model construction* level strategies. In total, this study identified 39 individual conversational strategies from the whole-class discussion transcripts of these educators. While space in this article does not permit sharing of the complete collection, the table below does highlight four more of these strategies. The table follows a classification system that increases in specificity from left to right: It starts with the four Level 3 *model construction cycle* phases on the extreme left then lists a specific Level 2 *cognitive model construction* strategy believed to contribute to each of the phases in the second column. The final column provides an example of each of the strategies from the transcript of one of the teacher's classes.

Level 3 OGEM Cycle Phase	**Level 2 Cognitive Model Construction Strategy**	**Classroom Transcript Example**
O Observation	Requests patterns in observations	T: Okay. How about when you added a second resistor—what did you notice?
G Generation	Requests or provides an analogy	T: You've already seen one analogy about water flowing through pipes. Is there any other analogy you can think of that would explain why this filament would have higher resistance than this filament?
E Evaluation	Requests the running of a model and comparing to experimental data	T: What does the resistor do? S3: Insulate. It acts like an insulator— T: Acts like an insulator? Is that what you saw? S3: No, because some of the charge still gets through...
M Modification	Requests or provides concept integration	T: When we added a resistor to the circuit with one bulb, what did you notice? S5: The bulb got dimmer. T: Like when you added a second bulb to the circuit? S5: Yes—the same thing happened. T: So, that pretty much tells us that a light bulb is a type of resistor, at least in terms of their effects on other elements in the circuit.

Table 1 – Sample Cognitive Model Construction Strategies

Moving Forward

Based on the identification, description, and categorization of the cognitively focused discussion-based teaching strategies investigated in my research, I have recently begun the process of sharing this information with students in the secondary science stream of our postgraduate B.Ed. program at St. Thomas University. In my secondary science methodology courses, I have developed a seven-step process for developing the students' skills in leading effective whole-class discussions.

1) I begin by accessing the pre-service teachers' prior knowledge about leading discussions; uncovering their experiences and beliefs about the manner in which teachers ask questions, respond to student comments or queries, prompt students to examine and critique their own and peers' ideas, encourage students to develop plausible arguments for explanations, and foster students' revisions of their own reasoning once new evidence is presented. For research ethics purposes, this is done through an interview and survey process conducted by my research assistant.

2) By next introducing the future educators to video recordings and transcriptions from selected classroom segments of experienced science teachers, they become aware of the tasks teachers undertake when leading a class discussion. This can include such tasks as maintaining classroom management, providing a classroom culture that supports student contributions, managing technical and audiovisual supports, supporting student metacognition by having them think about their own thinking, and fostering a type of classroom conversation that allows students to make mistakes and learn through a process of idea evolution as opposed to getting the right answer first.

3) Once the pre-service teachers have had the opportunity to observe the discussion-leading strategies of exemplary veteran educators in the field, the next step is for them to try out some of the tactics for themselves. Their first occasion to do so is during peer-to-peer micro-teaching sessions on a science topic and grade level of their choice. In planning these 40-minute mini-lessons, the pre-service teachers are required to build in a whole-class discussion segment.

4) These in-class trial sessions are videotaped and copies are provided to the pre-service teacher and three classmates. Within a week of the in-class micro-teaching experience, the pre-service teacher meets with their three colleagues, who have each had an opportunity to review the video recording of the lesson. Using a rubric co-operatively developed in class, they make notes and comments that will be used for the basis of the discussion during the meeting, providing constructive feedback to their colleague.

5) At the end of the course, and just before they begin their teaching internships, the students participate in a second interview/survey process to evaluate any change in their knowledge and opinions about leading class discussions.

6) During their 8-week teaching practicum, the student teachers are encouraged to seek out opportunities to engage their students in the discussion-based co-construction of explanatory models for concepts within the curricula being taught.

7) Upon completion of their internships, the B.Ed. students participate in the interview/ survey process a final time to evaluate the impact that having a "real world" opportunity to practice their discussion-leading strategies had on their understanding and comfort with the techniques.

Contribution

As a result of the study described in this paper, two distinct levels of discussion-based teaching strategies have been identified: *dialogical* strategies that serve to support clear and open communication of student ideas through class discussion, and *cognitive model construction* strategies that are believed to foster students' development and refinement of explanatory models to support reasoning about scientific phenomena. Within the *cognitive model construction* category, 39 specific discussion-based teaching strategies have been identified, each of which contributes to one of four phases (Observation, Generation, Evaluation, and Modification) of a *model construction cycle* existing at a third strategy level. In this article, examples of eleven of these strategies have been provided.

Based on this research, a seven-step process has been developed to share the key elements of these teaching strategies, provide examples of their use from the classrooms of experienced teachers, and provide opportunities for pre-service science teachers to practise and receive peer and instructor feedback on their implementation. Ultimately, my hope is that these efforts will equip the secondary science educators emerging from our postgraduate B.Ed. program with specific strategies for fostering their students' construction and understanding of effective explanatory models for conceptually challenging ideas.

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