Using Research on Cognitive Discussion Strategies to Support Pre-Service Science Teachers' Model-Based Teaching Skills[1]

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Abstract

One of the eight core scientific practices identified by the Next Generation Science Standards (2013) to help learners construct understandings of abstract concepts is the development and use of *models*. In this study we focus on *explanatory mental models* which are internal cognitive representations of normally hidden mechanisms that can explain why phenomena in a system occur. Our group has studied the model-based strategies used by successful teachers in a wide variety of conceptually challenging K-12 science topics and we have converged on a set of thirteen key cognitively-focused discussion-based teaching strategies that are believed to support students' conceptual understanding of complex science topics. As a result, the most recent phase of our research has been the development and implementation of an eight-week model-based instructional unit for pre-service science educators that introduces these strategies. During the unit, the pre-service teachers conduct practice mini-lessons on a variety of topics that are video recorded and shared with their classmates for peer and self-evaluation. Evidence from pre and post-instructional surveys, is presented that indicates how the unit positively impacts the way the pre-service teachers view the use of whole class discussions as a vehicle for promoting students' construction of explanatory models.

Introduction

Most K-12 science curricula include an array of topics that present students with abstract and conceptually challenging ideas. This includes topics such as magnetism, electricity, erosion, planetary motion, natural selection, atomic theory, etc. One of the eight core scientific and engineering practices identified by the Next Generation Science Standards (2013) to help learners construct understandings of difficult concepts is the development and use of *models*. The term *model* has many uses, however in the context of the study described herein, a model in the broad sense is considered to be a simplified representation of a system, which concentrates attention on specific aspects of the system (Ingham and Gilbert, 1991). In this study we focus on *explanatory mental models* which are internal cognitive representations of normally hidden mechanisms that can explain why phenomena in a system occur (Schwartz & Black, 1996; Vosniadou, 2002; Clement, 2008). These theoretical, qualitative structures are hypothesized to support reasoning and understanding by simulating the structure and behavior of targeted systems in the real world and include such things as fields, molecules, waves, etc. (Johnson-Laird, 1983; Hafner & Stewart, 1995; Gilbert, 2011).

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If science teachers hope to employ explanatory model construction as a means of fostering students' understanding of abstract concepts, they must first develop their own familiarity with the processes and products of modeling. For our research team, providing support for model-based teaching has two major foci: 1) studies identifying the strategies used by experienced, successful teachers to foster model based learning, and 2) the application of these research findings in developing learning modules for pre and in-service teachers to acquire and practice these classroom skills. In this paper, we analyze an attempt to support the model-based teaching skill development of pre-service science teachers in a course at one of our institutions.

Theoretical Framework

Research in the area of model-based teaching and learning supports the notion that students can gain deeper understanding of scientific phenomena that occur on scales that are either too large or too small to be readily observed, occur at rates that are either too fast or too slow to be witnessed, or occur in hidden or concealed situations when they are given opportunities to develop explanatory models that help support their reasoning. Vosniadou (2002), Duit & Treagust (2003), McNeill & Krajcik (2008), Windschitl et al. (2008), Schwarz et al. (2009), and Gilbert (2011) agree that engaging students in the processes of developing explanatory models for phenomena such as chemical reactions, atomic structure, sound waves, and inheritance can play a significant role in promoting their abilities to understand and reason about such scientific concepts.

Our group has studied the model-based teaching of a wide variety and grade level of conceptually challenging K-12 science topics, ranging from upper elementary units on human circulation and respiration (Nunez-Oviedo et al., 2008), to middle level units on atomic theory and particle behavior (Price et al., 2011), to high school units on universal gravitation (Stephens & Clement, 2012) and circuit electricity (Williams & Clement, under review). Our work has resulted in the documentation of experienced teachers' efforts to facilitate engaging, inquiry-focused classroom discussions in order to foster students' abilities to construct workable explanatory models for the concepts they are learning.

We observed that in doing so, these teachers engaged students in four distinct phases of a model construction process. Starting from students' 1) *Observations* of phenomena and their prior knowledge about the concepts being explored, the teachers supported students' 2) *Generation* of explanatory models for the phenomena. It was further observed that teachers acted to scaffold students' repeated 3) *Evaluation* and 4) *Modification* of those models through the evolution of what Clement (2000) refers to as *intermediate models*. These intermediate models are viewed as stepping stones on a learning pathway to a *target model* or desired knowledge state that one wishes students to attain after instruction. We collectively refer to these four model construction process as the OGEM (*Observation, Generation, Evaluation, and Modification*) Cycle (Williams & Clement, 2010) as our research has shown students and teachers often engage in repetitive cycles of co-constructing, assessing, and repairing explanatory models for concepts under study.

Based on a constant comparison analysis (Strauss & Corbin, 1998) of student/ teacher dialogue from whole class discussions in a variety of model-based science classroom video recordings, we converged on a set of thirteen key discussion-based teaching strategies that were believed to support students' construction of explanatory models for the science topics they were studying We refer to these as Cognitive Model Construction Strategies (Williams & Clement, under review).

The chart below sub-divides the thirteen cognitive model construction strategies into the 4 general model construction processes that we refer to above as the OGEM Cycle. We describe the thirteen strategies as *Micro Level* strategies because we view each of them as being a sub-strategy for one of the *Macro Level* OGEM processes. While the examples of the strategies provided here originated from observations of the teaching and learning of circuit electricity in high school physics classes, we believe that the teaching strategies identified are general enough to have utility across a wide variety of science topic areas and grade levels.

Macro Level - OBSERVATION	
Micro Level Strategies	***Classroom Transcript Examples***
Requests or provides experimental observations	T: Well what's your evidence that it happens? At some point don't the bulbs cease to light? And the compass ceases to deflect? What's that indicative of?
Requests or provides diagram to help students recall results of an experiment	T: You had a compass under this wire, one under this wire, and one here. What did you notice about all three wires?

Macro Level - MODEL GENERATION	
Micro Level Strategies	***Classroom Transcript Examples***
Requests or provides the initiation of model construction	T: In what way do you think bulbs influence charge in a circuit?
Requests or provides a model element to explain specific observation	T: Okay, so same amount (of measured current). So, what does that tell you about the amount of charge moving through this wire, or the rate of charge movement through these wires?
Requests or provides new detail or elaboration of the model	T: What happens to charge when it gets to the bulb?
Requests or provides spatial direction of effect for increased precision	T: Tell me which direction charge is moving through the bottom half of that circuit S: Positive to negative. T: Charge is moving? S: From the bottom. T: On the bottom half. Would you all agree it's moving from right to left?
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?

Macro Level - MODEL EVALUATION	
Micro Level Strategies	***Classroom Transcript Examples***
Requests or provides experimental evidence to support or refute a model	T: She thinks that the top bulb should be brighter than the bottom bulb or lit longer. Do we have some evidence that would either support that or refute that?
Requests or provides the design of an experiment or thought experiment	Example 1: T: Could we design an experiment to check which of those things that were just proposed is happening? Example 2: T: What if we were to test that model by placing a compass under the wire on either side of the bulb? Would that tell us whether the bulb consumes charge?
Requests or provides running a model for prediction or evaluation	Example 1: T: So, if charge is moving around in a circuit like this and if charge is being changed into heat, what would you expect to see in the compass as you moved further and further in the circuit? Example 2: T: OK, so a couple of people have said it (charge flow) slows down. So that's why the compass needle doesn't move as far?
Requests or provides a discrepant question	T: Your idea is that the flow rate (of charges) in the wire between the long bulb and the short bulb is different, depending on what order they are in. Is that right? S2: Yes. T: But this other group says that the compass needle deflected the same amount regardless of the order the bulbs were placed in. So, what do you think about that? S3: I don't know. Maybe it (flow rate) is the same.

Macro Level - MODEL MODIFICATION PHASE	
Micro Level Strategies	***Classroom Transcript Examples***
Requests or provides additions or changes to the model	T: (referring to a two-syringe model for a capacitor) Can anybody think of a way to make the model better – maybe to account for the difference (between the model and the system being modeled?) S2: What might make it better would be if you could rig up some kind of aquarium pump thingy or something between the two syringes so that when you turned it on, one syringe would suck in and the other would push out.
Requests or provides differentiation between elements of models.	T: That's probably true. But *is heat the same as charge*? S6: Charge is like energy T: Does charge get changed into heat? Is that what we're thinking?
Requests or provides integration of two models or concepts	T: When we added a resistor to the circuit with one bulb, what did you notice? S: The bulb got dimmer. T: Like when you added a second bulb to the circuit? S: 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.
Requests or provides repair to or refinement of the language describing the model	S: I think it (the light bulb) absorbed some of the charge. T: Absorbed some of the charge. Anybody have anything else? What's another word for absorbs?

Table 1 – Discussion-Based Model Construction Teaching Strategies: Macro and Micro Levels

Study Context and Design

The identification and categorization of these model-based teaching strategies has led us to the point where we believe we have valuable pedagogical information to share with K-12 science teachers. As a result, the most recent phase of our research has been the development and piloting of an eight-week instructional unit for pre-service science educators in the one-year post-graduate degree program in the School of Education at St. Thomas University in New Brunswick, Canada. The instructional unit, which consisted of 16 two hour classes, was designed to develop the students' skills in leading effective model-based whole class discussions and employed the following components:

1) On the first day of the unit, we administered a survey we had developed to access the pre-service teachers' prior knowledge about model-based teaching and leading discussions. As can be seen from the copy of the survey questions provided in the appendix, the items gave the respondents the opportunity to select and rank teaching strategies that they believed would be most and least effective for supporting student learning about science concepts.

2) The instructional unit began by introducing the future science educators to a series of articles (van Zee & Minstrell, 1997; Hogan, 1999; Windschitl et al., 2008; Schwarz et al., 2009; Vosniadou, 2002; Chin, 2007; Clement, 2008) on whole class discussion techniques and model-based teaching and learning in science. These papers address such issues as: creating a classroom culture that supports student contributions, the nature of models and modeling, ways of encouraging students to develop plausible arguments for explanations, and fostering students` revisions of their own and peers' reasoning once new evidence is presented.

3) After an introduction to general discussion stimulating strategies, we introduced the set of thirteen cognitive model construction strategies identified through our analyses of experienced model-based teachers. The students watched video segments of the experienced model-based science teachers who participated in our previous studies. Transcriptions of the teacher/ student discourse from these videos were provided to enable the pre-service teachers to critically evaluate the kinds of discussion-based strategies that the teachers on the videos were utilizing. Next, diagrammatic representations that we developed for these classroom discussions were shared with the course participants in hopes that seeing the classroom conversations portrayed in this manner would allow them to start distinguishing between teaching strategies at the Macro (OGEM Cycle) and Micro (13 Cognitive Model Construction Strategies) levels described above.

4) Once the pre-service teachers had sufficient opportunity to observe the model-based discussion strategies of veteran educators in the field, the next step was for them to try out some of the tactics for themselves. Their opportunity to do so took place during the final four weeks of the unit in the form of peer-to-peer micro-teaching sessions on a secondary level science topic of their choice. Working in pairs to plan and facilitate these 40 minute mini-lessons, the pre-service teachers were required to build in a whole-class discussion segment during which they attempted to lead their colleagues' in the construction of explanatory models for a key concept of the lesson. Some of the topics they chose were: the human circulatory system, waves, ecological footprints, and chemical reactions.

5) One type of feedback that has been shown to impact student learning is that of peer evaluation (Guskey, 2009; Airasian et al., 2012). As such, the in-class mini-lessons were video recorded and

copies were provided to the presenting pair and four classmates. Within a week of their micro-teaching presentations, the pre-service teachers received feedback from their colleagues, who each had an opportunity to critically review the video recording of the lesson. Using a checklist co-operatively developed in class, the peer evaluators made notes and comments regarding specific teaching strategies that their colleagues had employed in their mini-lessons. Part A of the checklist focused on general classroom practices such as teacher verbal clarity and audibility, the teacher's awareness of student engagement and understanding, provision of differentiated learning opportunities, etc. However, Part B of the checklist provided opportunity for the peer evaluators to note general discussion-leading strategies that their colleagues had employed in their mini-lessons. In Part C of the checklist, peer evaluators were able to identify whether the presenters had utilized any of the thirteen cognitive model construction strategies that they had been introduced to in the course. Examples of the very detailed feedback that the pre-service teachers provided one another on these aspects of their lessons are demonstrated in a sample completed copy of the checklist included in the appendix.

6) Self-evaluation has also been shown to provide valuable formative feedback to students in the development of knowledge and skills (Airasian et al. (2012); Andrade (2007); Waugh & Gronlund (2013). The pre-service teachers also met with their mini-lesson co-facilitators to review the video recording, review the comments on the peer-evaluation checklists, and discuss improvements they could make in their teaching practice. This process is further discussed later in the paper.

7) At the end of the eight-week course, and just before they began their first of two nine-week practice teaching internships, the students participated in a second survey process to provide them an opportunity to reflect on what they had experienced in the instructional unit and also to determine whether any changes had occurred in their knowledge and beliefs about using class discussions as a means of fostering students' construction of explanatory models.

A description of the methodology used in comparing the pre and post-instruction survey data and the results of this analysis are presented in the following section.

Data Analysis & Results

Comparisons of the pre and post-instruction survey responses for the 17 science education students who participated in the survey were done to establish whether any statistically significant gain differences existed between the pre-service teachers' responses on the pre and post-instruction surveys, indicating that the 8 week unit may have contributed to a change in their thinking about the role of whole class discussions in supporting students' construction of explanatory models.

For questions 1 and 3, in which the students were asked to rate their opinion of the usefulness of a variety of teaching strategies as being either Very Useful (V), Useful (U), Somewhat Useful (S), or Not Useful (N), the responses were coded numerically as follows: V=4, U=3, S=2, and N=1. In question 6 regarding how teachers should respond to a student expressing a misconception during a whole class science discussion, the survey responses were coded as follows: Correct it immediately = 1, Simply praise the student for contributing an idea = 2, Ask the other members of the class what they think about the idea = 3, and Choose one of the above responses on the basis of the nature of the misconception itself = 4. The responses were coded in this way since this represented our impression of the increasing effectiveness of these strategies for supporting students' conceptual change. Similarly, for question 7 which addressed the students' beliefs that "correct" models can be constructed from earlier student models that are incorrect in significant ways, the responses were coded as follows: Completely agree = 4, Somewhat agree = 3, Somewhat disagree = 2, and Completely disagree = 1. This coding choice was based on our belief that this kind of evolution of model correctness is indeed possible and highly desirable, as evidenced in the science classrooms we have investigated. For survey questions 2, 4, and 5 which addressed the percentages of time that pre-service teachers felt should be spent on certain types of teaching activities, since the responses were already provided in numerical form, no additional coding was required.

A paired t-test with a Confidence Interval of 95% was used to establish for which question response averages a statistically significant change occurred between pre and post-instruction surveys. As a result of the statistical analyses, it was determined that the following survey question responses showed significant changes from pre to post-instruction:

Question Number	Question	Pre-Instruction Survey Avg.	Post-Instruction Survey Avg.	Change
1c	Rate your opinion of the usefulness of whole class discussion in science classes	3.25/4.0	3.82/4.0	+0.57
1e	Rate your opinion of the usefulness of simulations in science classes	3.25/4.0	3.82/4.0	+0.57
2a	What percentage of class time do you think science teachers should spend on lecture/ presentation/ demo (teacher talk)?	36.3/100	18.2/100	-18.1
2b	What percentage of class time do you think science teachers should spend on whole class discussion?	18.2/100	35.8/100	+17.6
3e	Rate your opinion of the importance of fostering scientific reasoning as a purpose for whole class discussions.	3.55/4.0	3.94/4.0	+0.39
3g	Rate your opinion of the importance of having students make predictions as a purpose for whole class discussions.	3.15/4.0	3.82/4.0	+0.67
3h	Rate your opinion of the importance of focusing students on explanatory models a purpose for whole class discussions.	3.05/4.0	3.94/4.0	+0.89
3i	Rate your opinion of the importance of having students generate explanatory models as a purpose for whole class discussions.	3.05/4.0	4.0/4.0	+0.95
3l	Rate your opinion of the importance of engaging students in thought experiments as a purpose for whole class discussions.	3.3/4.0	3.76/4.0	+0.46

3m	Rate your opinion of the importance of allowing students to evaluate explanatory models as a purpose for whole class discussions.	3.0/4.0	3.88/4.0	+0.88
4	What percentage of the ideas considered in whole class discussions do you feel should be teacher generated vs. student generated?	50% vs. 50%	32% vs. 68%	18% shift toward students
5	What percentage of the evaluation of ideas during whole class discussions do you feel should be done by teacher vs. students?	51% vs. 49%	41% vs. 59%	10% shift toward students
7	Rate your level of agreement with the statement, "Through whole class discussion, correct models can be constructed from earlier student models that are incorrect in significant ways."	3.30/4.0	3.76/4.0	+0.46

Table 2 – Survey Question Response Averages with Statistically Significant Pre to Post-Instruction Gains

Discussion

Compared to the pre-instruction surveys conducted at the outset of the eight week instructional unit described above, a number of the post-instruction responses provided by the pre-service secondary science education students indicated statistically significant changes in their beliefs about the best ways to foster learners' construction of explanatory models for scientific concepts. The following are hypotheses as to why some of these gains may have occurred.

In Question 1 of the survey, the two teaching techniques that the students reported the greatest increase in their support for were: c) whole class discussions, and e) the use of simulations. This is not at all surprising since the majority of the course readings and the video clips of experienced teachers used during the course focused on the usefulness of whole class discussions to support students' construction of explanatory models for science concepts. In many of the articles and videos both physical and computer generated simulations were suggested as means for fostering student reasoning.

In the second survey question, the focus was on determining what portion of a typical science class the pre-service teachers believed should be spent on engaging the students in various learning activities. On the pre-instruction survey, the group reported on average that they believed 36% of class time should be spent on teacher talk (lecture, presentation, demo) and 18% should be spent engaging students in whole class discussions. After the eight week instructional unit, these values flipped to 18% of class time being spent on teacher talk and 36% being spent on whole class discussions. These were both assessed as being statistically significant changes over time. While this is also not surprising considering the strong emphasis during the course on classroom conversations as a teaching method, it is encouraging to see that the future science educators recognized the importance of a shift from teacher-centered to student-centered pedagogy.

Subsequent to this, Question 3 of the survey polled the emerging teachers' perceptions of the usefulness of whole class discussions in supporting various student learning activities and skills. Statistical analysis determined that the following purposes for whole class discussions gained significant support from the group over the course of the instructional unit: fostering students' scientific reasoning, having students make predictions, supporting students' generation and evaluation of explanatory models, and engaging students in thought experiments. Again, it is promising to see that the science education students gained an appreciation for teaching strategies that are designed to promote student-centered reasoning through an evolutionary process of constructing, thinking about, discussing, testing, and revising explanatory models. These are precisely the types of practices that the NGSS (Next Generation Science Standards) advocate for meaningful student learning in science.

Questions 4 and 5 of the survey address the issues of who should be leading and participating in the model construction activities described above. On the pre-instruction version of the survey, the pre-service science teachers reported on average that they believed teachers and students should be equal partners in the generation of explanatory models for science phenomenon. After the course, the consensus was that students should contribute 68% of these explanations and teachers only 32%. This represents a statistically significant change in the emerging teachers' belief about who the primary idea generators should be during science classes. Similarly, the post-instruction surveys revealed that the upcoming science educators believed that students should contribute to the evaluation of explanatory models at a rate of 59% as compared to having teachers do so only 41% of the time. This represents a statistically significant shift from the pre-instruction survey towards increased student participation in this important activity. These two findings are consistent with research by Windschitl et al. (2008), Schwarz et al. (2009), Nunez-Oviedo et al. (2008), and Price et al. (2011) suggesting that students should be at the center of such model construction and revision activities.

Finally, the responses to survey Question 7 indicate that the secondary science education students involved in this study experienced significant gains in their belief that even though students often start out with misconceived, incomplete, or flawed explanatory models for scientific phenomena, through carefully planned instruction, these alternative conceptions can be gradually brought in line with the scientifically accepted target models. This aligns with the substantial body of research on student conceptual change supporting the notion that science learning is a step-wise process of considering, testing, discarding and re-imagining explanations and solutions on the path to understanding.

The Peer and Self-Evaluation Process

While the influence of the course readings, class discussions, and video recordings of experienced model-based teachers during the eight week instructional unit described herein cannot be overlooked, we suggest that the pre-service science teachers' participation in the planning, facilitation, and peer and self-evaluation of one another's and their own in-class mini lessons contributed considerably to the evolution of their thinking about the types of teaching strategies that impact students' reasoning about abstract science concepts.

In an effort to gain the peer-evaluators' perspective on their role in the process, at the end of the course, a focus-group of participants from the course was established in order to better understand their peer and self-evaluation practices and question them about the experience. Using their laptop computers and a copy of one of the mini-lesson video files, the students were asked to demonstrate the manner in which they evaluated their peers' teaching efforts. In order to capture their thoughts during the evaluation process, the students were asked to "think-aloud", describing what they were doing. The students were also interviewed about their impressions of the peer-evaluation process and their role in it. These think-aloud sessions and interviews were video recorded for review and analysis. Below are excerpts from the think-aloud peer-evaluation reflections and interviews:

In this first clip, one of the peer-evaluators explains the technical process he utilized when reviewing the mini-lesson video on his laptop computer.

"So what I like to do when I'm reviewing these mini-lessons, is I put the video on one side of my computer screen and then I have my evaluation sheet to work on, on the other side. So, I can see the video on one side of my screen and I can type at the same time and if I need to, I can stop and pause the video to collect a thought in case I don't want to miss the next thing coming up."

Next, another peer-evaluator provides a step-by-step commentary of the mini-lesson she was evaluating.

"So for their activity, the two teachers here are doing a good job incorporating materials to have students who are kinesthetic learners have hands-on equipment. And they are allowing students to work in groups to discuss their own explanatory models with each other. This activity was a good one to get students to examine their pre-conceptions before they reconvened back into a whole class discussion"

In interviewing the students on their roles as peer-evaluators, one pair had the following to say:

Interviewer: "What did you find was the most difficult part of being a peer-evaluator, using the evaluation form, and going through this whole evaluation process?"

Renee: "I thought it was difficult sometimes to identify whether the teachers, my classmates, were actually using some of the cognitive model construction strategies we learned about. I found that I had to watch the video several times to find some examples because they are pretty subtle and sometimes the students don't necessarily pick up on what we (the teachers) are trying to get them to do. I think we will get better at this with practice but it is good to see people trying.

Joe: "My approach was moreso as I watched the video and I heard a comment or observed a certain strategy being employed, I would pause the video and go to the checklist right away and find where that applies, like in which of the four OGEM macro strategies. Then I would type up my comments and I might use a quote from the classroom conversation as evidence. I feel like that approach is pretty practical because right there in the moment you can have it and you don't always remember that from the lesson alone. That's why it's nice to have the video to see that."

Reflections on the Self-Evaluation Process

In addition to the feedback received from their peer-evaluators, the mini-lesson facilitators participated in a self-evaluation of their teaching efforts. This was a two-step process in which the pair met to: 1) review the video recording of their mini-lesson and engage in open commentary about what they observe, and 2) review the completed checklists from the peer-evaluators to compare comments and to reflect on the suggestions made.

The following is a conversation between two mini-lesson facilitators as they reviewed their video for the first time.

Sarah: "I think we have good awareness of the classroom, we're using the space very well."

Brett: "Yeah, I think we did. We didn't just stay in one space, we moved throughout the room and I think it kept the students engaged."

While they were reviewing the peer-feedback evaluation forms, this same pair of mini-lesson presenters had the following to say:

Brett: "One thing I noticed really we were quite weak on was promoting student-to-student interaction. It was all pretty much us (teachers) and them (students)."

Sarah: "Right."

Brett: "It's going to have to be something we develop, getting them to talk about each other's explanatory models."

Sarah: "Yeah, I see the same thing on this evaluation. It says we didn't really give the students a chance to evaluate each other's models. The evaluator recommended using different techniques, like instead of just student to teacher dialogue, maybe using some volleyball style student to student conversation. That's something we could try in the future."

In discussing their participation in these peer and self-evaluation exercises, the students made the following comments about the impact on their teaching skills:

Interviewer: "So how does participating in these peer and self-evaluation activities make you better as an emerging teacher, getting ready to start your first practice teaching field placements?"

Renee: "I think you can learn a lot from watching yourself. As much as I hated being videotaped, you learn a lot about what you do; your mannerisms, the things you say too much, that kind of stuff. So, definitely what you need to work on and what you're doing well. It will help you when you can see that."

Joe: "It's actually, like, confidence building for those moments. Because, for some of the moments you just put your head down and say, 'Wow – I just tripped over myself there', but then other times you're like, 'Wow – I really had really had the kids engaged in generating models for that concept and thinking of many different possibilities'. So, it can be confidence building too."

Brett: "Having worked in the chemical industry before deciding to become a teacher, I can tell you that the majority of professionals I have encountered are generally not good facilitators of group discussions, they know their stuff but they don't necessarily do a good job sharing ideas with others. This peer-evaluation process has given me the opportunity to learn what makes for good teaching and discussion-leading skills and has allowed me to both provide and receive critical feedback from my colleagues in the class."

Sarah: "I know that in my undergrad degree I had to do class presentations, but we never had a chance to get formative feedback on a level like this. I think the prof just gave us a grade based on what he or she saw in class, but having four of your peers take the time to review the entire *mini-lesson and critically review it with a checklist is way more helpful than just having the prof evaluate you. I have become aware of so many more aspects of my teaching skills this way."*

During their upcoming teaching practicums, the student teachers are being encouraged to seek out opportunities to engage their students in discussion-based co-construction of explanatory models for concepts within the science curricula being taught. Upon completion of their internships and return to the university for continued coursework, the students will participate in a final interview/ survey to evaluate the impact that having an authentic classroom opportunity to practice their model-based discussion-leading strategies had on their understanding and comfort with the techniques. It is expected that the realities of authentic public school classrooms will challenge the emerging science teachers in ways that their artificial micro-teaching experiences could not, so it will be interesting to determine in what ways they believe they were able to implement the model-based teaching strategies they explored during the coursework described herein.

Conclusion

K-12 science topics such as magnetism, electricity, erosion, planetary motion, natural selection, atomic theory, etc. require students to grapple with very abstract and conceptually challenging ideas. One of the eight core scientific and engineering practices identified by the Next Generation Science Standards (2013) to help learners construct understandings of difficult concepts is the development and use of *models*. Our research team has documented experienced teachers' abilities to facilitate engaging, inquiry-focused classroom discussions in order to foster students' abilities to construct, evaluate, and revise workable explanatory models for the concepts they are learning.

Analysis of the student/ teacher dialogue from whole class discussions of veteran K-12 science teachers in our previous studies have led us to the identification of thirteen of what we refer to as Cognitive Model Construction teaching strategies intended to support the students' conceptual understanding. We describe the thirteen strategies as *Micro Level* strategies because we view each of them as being a sub-strategy for one of four *Macro Level* OGEM processes. OGEM is an acronym that describes the four distinct phases of model construction processes we have observed in previous studies (Williams & Clement, under review). Starting from students' 1) *Observations* of phenomena and their prior knowledge about the concepts being explored, the teachers supported students' 2) *Generation* of explanatory models for the phenomena. It was further observed that teachers acted to scaffold students' repeated 3) *Evaluation* and 4) *Modification* of those models through the evolution of what Clement (2000) refers to as *intermediate models*. These intermediate models are viewed as stepping stones on a learning pathway to a *target model* or desired knowledge state that one wishes students to attain after instruction.

Based on these findings, the most recent phase of our research has been the development and implementation of an eight-week instructional unit for pre-service science educators in the one-year post-graduate education degree program at in the School of Education at Saint Thomas

University in New Brunswick, Canada. The instructional unit was designed to develop our students' skills in leading effective model-based whole class discussions and employed a variety of learning activities such as journal article reviews, classroom videotape observations, teacher/ student transcript analyses, teacher strategy identification exercises, classroom discourse diagramming assignments, and peer and self-evaluated micro-teaching sessions.

Through the quantitative analysis of pre and post-instruction surveys, we have assessed the areas of pre-service teacher thinking that appear to have experienced the greatest changes throughout the course. We note that the science education students seem to have gained an increased appreciation for centering science instruction on the learner, starting from students' prior knowledge, and engaging them in an evolutionary process of developing, considering, and revising explantory models to help them better understand abstract science concepts and phenomena. We believe this is a move in the right direction as many studies have shown science instruction that engages students in reasoning about explanations and solutions to problems supports deeper and longer-lasting understanding.

A review of the peer and self-evaluation of in-class mini-lesson teaching experiences has offered valuable insights into the importance of providing pre-service teachers with opportunities to practice and critically asses their model-based teaching practices before embarking on authentic classroom experiences. By engaging course participants in a post-instruction focus group process, we are learning of the challenges that emerging science teachers face in learning how to engage students in the construction of explanatory models. This appears to be a process that requires considerable patience and practice and one that is well supported by collegial sharing and feedback.

It is believed that this study's contributions to an understanding of both model-based teaching and whole-class discussion leading strategies can support the work of teachers and teacher educators by dividing the extremely complex act of science teaching into several basic sets of learnable skills. It is hoped that in sharing our own experiences of putting our research findings into action in one of our science teacher preparation programs and describing our model of peer and self-evaluation of specific cognitive model construction strategies in video recorded mini-lessons, we can further a shared understanding of what constitutes effective science teaching and learning.

Appendix

Pre and Post Instruction Survey Questions

1) For each of the following teaching/ learning techniques, please rate your opinion of their value in science classes: Very Useful (V), Useful (U), Somewhat Useful (S), or Not Useful (N).

Teaching/ Learning Technique	Rate Your Opinion
a. Small Group Experiment	
b. Small Group Discussion	
c. Whole Class Discussion	
d. Analogies	
e. Simulations	
f. Teacher Demonstrations	
g. Diagrams	
h. Individual Problem Solving	

2) Aside from classroom management and housekeeping activities, what percentage of class time do you think science teachers should spend on each of the following activities? Please ensure a total of 100%.

Activity	% of time spent on this
a. Lecture/ presentation/ demo (teacher talk)	
b. Whole class discussion	
c. Small group work	
d. Individual student work	

3) The following is a list of suggested purposes for whole class discussions. Rate each as being Very Important (V), Important (I), Somewhat Important (S), or Not Important (N)

Suggested Purposed for Whole Class Discussion	Rate Your Opinion
Reviewing correct knowledge that students have already been introduced to	
Uncovering student ideas, no matter how incorrect	
Providing diagnostic information for the teacher	
Allowing students to ask the teacher for information	
Fostering scientific reasoning	
Reviewing material learned from the textbook	
Having students make predictions	
Focusing students on explanatory models	
Having students generate explanatory models	
Reaching closure on target concepts and correct answers to questions	
Revising students' ideas to become less incorrect	
Engaging students in thought experiments	
Allowing students to evaluate explanatory models	
Allowing students who have learned the material to get positive feedback from the teacher	

4) What percentage of the ideas considered in whole class discussions do you feel should be teacher generated vs. student generated? (ie: 60% vs. 40%, 30% vs. 70%, etc.)

__________________ vs. ____________________

Teacher Generated Student Generated

5) What percentage of the evaluation of ideas during whole class discussions do you feel should be done by teacher vs. students? (ie: 60% vs. 40%, 30% vs. 70%, etc.)

__________________ vs. __________________

Teacher Evaluated Student Evaluated

6) Select what you feel is the single best response to this statement. When a student voices a misconception in a whole class discussion, the teacher should:

Teacher Action	**Select One Only**
a) Correct it immediately	
b) Simply praise the student for contributing an idea	
c) Ask the other members of the class what they think about the idea	
d) Choose one of the above responses on the basis of the nature of the misconception itself	

7) Rate your level of agreement with this statement.

Through whole class discussion, "correct" models can be constructed from earlier student models that are incorrect in significant ways?

Completely agree	
Somewhat agree	
Somewhat disagree	
Completely disagree	

Science Mini-Lesson Peer Evaluation Checklist – Part A

Lesson Facilitators: Sarah and Jennie   Date: October 21st, 2013

Observation by: Eric   Grade: 6   Topic: Animal Classification

Rating Scale:

1 **Weak** – below satisfactory performance, considerable improvement required
2 **Adequate** – satisfactory performance, some improvement required
3 **Good** – competent performance, only minor improvement required
4 **Strong** – more than competent performance
5 **Exemplary** – outstanding performance

Look For	Rating	Comments
PRESENTATION		
The teachers have clear and audible verbal presentation	4	You both were perfectly audible throughout the entire presentation. Great teacher voices!
The teachers move freely and frequently about the learning space	5	Great circulation at the beginning of the lesson when we were working on our classification systems. Later when we had a discussion on the different groups of animals, you both were stationary at your whiteboards, which was great because you were situated at two different locations in the classroom.
The teachers employ non-verbal interaction techniques with students	4	You both were smiling throughout the entire lesson and had great eye contact with the class. Neither of you appeared at all intimidating. You were both very approachable!
The teachers exhibit an awareness of participants' engagement	4	Throughout the classification activity at the beginning of the lesson, you both circulated the classroom and ensured that everyone was participating and asked students to explain what they were doing/how we were classifying.
The teachers address students on an individual basis (uses their names)	4.5	Throughout the entire lesson, each of the students was addressed using their first names when they wanted to answer a question. Great job!
The teachers exhibit a positive and enthusiastic teaching attitude	5	You both appeared very enthusiastic about the lesson. You were also very confident with what you were teaching and were not all intimidating or judgmental when addressing our questions or answers. You both did great job of establishing a positive learning environment!

Look For	Rating	Comments
CONTENT		
Early in the lesson, the teachers articulate the concepts that will be addressed	4	At the start of the class, you did a great job of introducing the topic as well as the agenda for the lesson. Jennie: “We are going to be learning how to classify different animals and what traits can be used to do so”. Sarah: “You will be learning about what a classification scheme is and why we use them”.
The teachers utilize activities/ strategies that are crafted to lead to the understanding of those concepts	5	The start-up activity was great for showing us how certain objects can be classified in different ways based on different characteristics. The class discussion was very good for making a student-generated classification scheme for the 5 different animal groups. Fantastic!
The teachers identify student misconceptions and consider them	4	21:25: Colleen: “Birds have wings and can fly”. Jennie: “But do all birds fly?” Class: “No”. Jennie: “So do we want to use that as a classification for birds?” 17:00: After asking students to come up with groups of animals. Student: “Insects?” Sarah: “That’s a very good answer, but insects are actually considered invertebrates”.
The teachers assess student understanding in a systematic, varied and ongoing manner	3	Although I thought it was great that we were given the chance to get into an interactive activity right away, I think the classification activity could have been more beneficial at the end of the lesson, as some grade 6 students may have difficulty with classifying objects based on characteristics before learning about it in class (I could be wrong though, maybe students have been introduced to object classification in other classes/grades??). It would also be a great way of letting students apply what they have learned in class to something other than animals (connection to everyday life). Aside from that you both did a great job of ensuring that we understood the concepts being taught. For example, during our discussion on invertebrates vs. vertebrates, once students give examples of invertebrate animals, Jennie asks: “And why again are these animals considered invertebrates?” Students: “Because they don’t have a backbone.” Jennie: “They don’t have a backbone, right!” Great! The activity on the computer was also a great way of assessing our understanding of classification, especially since it introduced new characteristics!

The teachers use representations, abstractions, and models as appropriate	3	Although phylogenetic trees might be something that would have been done in following lessons, I would strongly recommend introducing tree-like representations/models for animal classification just to get students thinking about that concept. However, I do appreciate that this would be an introductory lesson, and that there was a time limitation. Aside from this, the start-up activity was a great representation of classification schemes for everyday objects (great connection to everyday life!).
The teachers appear knowledgeable about the topic and its connection to the course	4	It is evident that you both had done your research on the topic as you were very knowledgeable! Not only were you able to answer each of the students' questions with ease, you also did a great job of guiding our discussions in the right direction so that we could classify each of the animal groups ourselves. Fantastic job, I was really impressed!

Look For	Rating	Comments
IMPLEMENTATION		
Students are given opportunities to apply existing knowledge to new situations and integrate new and prior knowledge	4.5	The class discussion was a good way of using prior knowledge of the different types of animals that exist and applying this to the classification of vertebrates into 5 groups. The activity at the end on the computer was a great way of applying our newly acquired knowledge to an interactive activity in which we can sort characteristics based on an animal classification scheme. If done later in the lesson, the start-up activity would be great for integrating new knowledge of classification schemes with prior knowledge of everyday objects/food, etc. (see previous comment).
Students are given opportunities to do more than follow procedures – they ask their own questions, choose their own strategies, or design investigations	4	Students were not really told to follow any specific directions. Rather, students were able to build classification schemes for objects (start-up activity) in any way they wanted. Students were also given the opportunity to draw an animal or create their own, that they could then place into one of the 5 animal groups that we had established. Overall, everything was very student-centered, great job!
Students are given opportunities to manipulate materials and equipment	4.5	Students were able to use the interactive classification game on the computer, which was great. However, only a few students were able to do so. The start-up activity allowed students to

		manipulate paper-cut outs to build their own classification schemes. There was not a huge amount of manipulation, though I do appreciate that it can be quite difficult to do so with this topic.
Students are given opportunities to utilize higher-order thinking skills through evaluation, synthesis and creation.	4.5	The activity at the start allowed for students to analyze a group of objects and group them up according to similar characteristics in order to create their own classification scheme. Students were then prompted to evaluate the classification schemes of other groups and attempt to determine how the objects were sorted.
Students' contributions are incorporated into the lesson	5	16:45: Sarah: "Louis brought up a very good term earlier – Mammals. Now can anyone give some animal characteristics that might be unique to mammals?" 24:00: Sarah: "So, when you guys were classifying your instruments, there was a little bit of discretion of what a piano is. This sometimes happens when looking at such a large system, but here we are more so looking for the *function* of the skin, rather than its structural characteristics (blubber, fur, etc.). Great job!
Students are provided a variety of differentiated learning opportunities	5	The start-up activity is great for kinesthetic, visual and auditory learners because they are building a classification scheme (kinesthetic) to sort the different objects on paper (visual) while they discuss in groups and as a class how the objects should be classified/sorted (auditory). The classroom discourse on animal classifications was another great activity for auditory learners (great discussion!)
Students are provided adequate time to complete the learning activities	4	The entire lesson was very well paced. Each activity was allotted just enough time to complete the activity without straying off topic. Good Job!
Students are given opportunities to reflect on their learning in a formative way	5	The reflective activity at the end of lesson was a great conclusion! Drawing our favorite animal or creating our own imaginary animal and placing it under one of the animal groups really got us to reflect back on what we had learned throughout the lesson. Awesome!

Total Rating: 86/ 100

Science Mini-Lesson Peer Evaluation Checklist – Part B

Whole Class Discussion Leading Strategies

Strategy Used	Comments
Establish a safe environment	All answers were accepted without judgment and you made every student's contribution to the conversation seem relevant and valued (see examples below for student contributions).
Raise a key question	"Why do we classify organisms?" "Why would we want to do that?"
Adjust the question	13:30 "Does anyone want to volunteer and explain this group's classification system?" … Silence… "Does anyone see how they sorted the objects or know why they sorted them this way?" 14:45 Sarah: "Can anyone hypothesize what those two categories were?" Jeremy: "Water and Land" Sarah: "I'm thinking more so what were the two animal kingdoms?" Jennie: "Remember to look outside of just animals too." Great Job!
Withhold answers	No answers were withheld.
Defer judgment	In the example below at 23:00 minutes in "Appreciating student contributions" Jennie has deferred her judgment on the topic of metamorphic life cycles, but has mentioned that this is an interesting point to keep in mind. Great!
Appreciate student contributions	21:00: Ben: "They have metamorphic life cycles". Jennie: "Can you explain to the class what a metamorphic life cycle is?" Ben explains… Jennie: "Perfect, that's a great definition of it!" 23:00: Ben talks about how fish are half bone/half cartilage. Although this was not to be covered in that day's lesson, Jennie responds with: "That's a really interesting fact for us to think about!"
Provide Wait/ Think Time	2:20: A good wait-time of ~8 seconds was given to answer the question: "Does anybody know why we classify organisms?"

Ask Low Cognitive Demand Questions	14:40: Sarah: "There were originally only two categories of organisms that were classified on earth. Can anyone tell me what those two categories were?"
Use a traditional I R E Sequence (Ping Pong)	16:00: Jennie: "What is the difference between vertebrates and invertebrates?" Justin: "They have a vertebrae". Jennie: "And what's a vertebrae?" Justin: "A spinal cord". Jennie: "Yes, exactly." 16:25: Jennie: "Who can give me some examples of animals that are invertebrates?" Students: "Sea cucumbers" "Jellyfish"… Jennie: "Yes, exactly".
Probe	Jennie: "Why do we classify organisms?" Julie: "To find similarities between animals." Jennie: "Why do we want to do that?" 19:00: Jennie: "Can you maybe go into a little bit more detail and explain this to the class?" after Corry mentioned the term "endotherm".
Use a Reflective Toss	18:10: Sarah: "What are some of the characteristics that are unique to the group of mammals?" Student: "They have fur". Jennie: "Why do they have fur?" Student: "To regulate temperature and keep warm." Jenny: "And what could you build off of that?" Great sequence of reflective tosses! 16:20: Jennie: "What is the difference between vertebrates and invertebrates?" Justin: "They have a vertebrae". Jennie: "And what's a vertebrae?"
Mark/ Amplify/ Paraphrase	16:20: Jennie: "And why again are they considered invertebrates?" Students: "Because they don't have a backbone". Jennie: "They don't have backbones, right! So, again like you said, vertebrates are animals with backbones, and invertebrates are animals without backbones."
Encourage Student to Student Talk (Volleyball)	17:00: Sarah: "Can anybody think of any other groups of animals that we have?" Julie: "Birds" "Reptiles" "Amphibians" "Fish" …. Sarah: "Yes!"
Scaffold Academic Language	19:15: Jenny: "So what might be a more simpler term that we can use to describe this?" … "Warm-blooded, great!"
Voting	31:00: Jenny: "Everyone raise your hand if you think that webbed feet belong in the amphibians group […] Great, that seems to be the class consensus!"

Science Mini-Lesson Peer Evaluation Checklist – Part C

Model Construction Strategies

Macro Level	Micro Strategy Used	Comments
Observation	Request or provides experimental observations	You requested for any observations of general animal characteristics. For example: 18:00: Sarah: "Can someone give me a characteristic of a mammal that might be unique to that group?" 21:25: Colleen: "Birds have wings and can fly". Jennie: "But do all birds fly?" Class: "No". Jennie: "So do we want to use that as a classification for birds?"
	Requests or provides diagram to help students recall results of experiment	You set up columns on the white board for each group of animals so that we could categorize animal characteristics.
Generation	Requests or provides the initiation of model construction	The start-up activity asked that we build a model of a classification scheme using the assortment of objects we were given.
	Requests or provides a model element to explain specific observation	This strategy did not appear to be used
	Requests or provides spatial direction of effect for increased precision	This strategy did not appear to be used
	Requests or provides new detail or elaboration of the model	Jennie: "Why do they have fur?" Student: "To regulate temperature and keep warm." Jennie: "And what could you build off of that?"
	Requests or provides an analogy	The classification systems that we had made using the assorted objects at the beginning of the lesson were a great set of analogies for classifying animals.

Macro Level	Micro Strategy Used	Comments
Evaluation	Requests or provides experimental evidence to support or refute a model	This strategy did not appear to be used
	Requests or provides the design of an experiment or thought experiment	Had all the students in the class evaluate one another's classification schemes. Example: 11:25: Sarah: "Eric, can you tell me how they classified their instruments?"
	Requests or provides running a model for prediction or evaluation	This strategy did not appear to be used
Modification	Requests or provides additions or changes to the model	25:30: Sarah: "You guys have a great list started […] What we are going to do is play a game on the computer that will go through some of the characteristics of these five groups. So we are going to ask Ashley and Louis to add any details from the game that we don't already have, to make our list more inclusive." Awesome!
	Requests or provides differentiation between or integration of elements of models.	24:25: Sarah: "So, reptiles and amphibians are somewhat similar. What would be some defining characteristics that would help us distinguish between the two groups?"
	Requests/ provides repair to or refinement of the language describing the model	19:15: Jenny: "So what might be a more simpler term that we can use to describe this?" … "Warm-blooded, great!"

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