Influencing Pre-Service Science Teachers' Beliefs About Model-Based Whole-Class Discussions

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Introduction

Most secondary science curricula include topics that present students with abstract and conceptually challenging ideas. This includes topics such as magnetism, electricity, erosion, planetary motion, natural selection, and atomic structure. One of the eight core scientific and engineering practices identified by the Next Generation Science Standards (2013) to help learners construct understandings of abstract and conceptually challenging topics is the development and use of *models*.

The term *model* has many uses, however in the context of this study, a model is considered to be a simplified representation of a system, which concentrates attention on specific aspects of the system (Ingham and Gilbert, 1991; Johnson-Laird, 1983). Russ et al. (2008), diSessa (1993), Hafner & Stewart (1995) and Schauble (1996) describe conceptual mental models as being causal and mechanistic while Kenyon et al. (2011) refer to them as “idea models”.

Herein we focus on *explanatory mental models* which are internal cognitive representations of normally hidden mechanisms that can explain why phenomena in a system occur (Clement, 1989; Vosniadou, 2002). The explanatory mental models examined in this article are qualitative structures that are hypothesized to support reasoning and understanding by simulating the underlying hidden structures and functioning of targeted systems in the world and include such things as fields, molecules, waves, etc. (Clement, 2008; Gilbert, 2011; Nersessian, 2008; Schwartz & Black, 1996).

Unfortunately, many teachers have limited knowledge of students’ understanding of models and modelling and often little comprehension of scientific modelling themselves (van Driel and Verloop, 2002). 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 exploratory case study, we analyze our first attempt to introduce the concept of explanatory models, modeling processes, and associated teaching strategies to pre-service science teachers in a course at one of our institutions. This course attempted to go much more deeply into cognitive and dialogical aspects of discussion leading for model-based teaching than is normally done so we were interested in collecting evidence on whether this influenced the students' model-based teaching beliefs and practices. In doing so we also hope to introduce readers to the concept of multiple levels of strategies for discussion leading.

Theoretical Framework

Research by McNeill & Krajcik (2008), Windschitl et al (2008), Schwarz et al. (2009), Vosniadou (2002), Duit & Treagust (2003), and Gilbert (2011) supports the notion that when students are given opportunities to develop explanatory models, they can gain a deeper understanding and ability to reason about abstract scientific concepts. One method for supporting students' participation in the construction of explanatory models is the use of whole class discussions. Research by Hammer (1995), Hogan & Pressley (1997), Roth (1996), van Zee and Minstrell (1997), and Chin (2007) has identified some general strategies teachers use during whole-class discussions in order to promote student engagement and communication. These include: participating mainly as a facilitator in the discussion, restating or summarizing student statements, choosing to not directly challenge "incorrect" statements, redirecting questions back to students rather than providing answers, focusing attention on conflicts and differences of opinion, and inviting responses to other students' statements.

We refer to these kinds of strategies as being *Dialogical* in nature since they are not aimed at specific kinds of conceptual learning, but rather are intended to support dialogical interaction in general, 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. These research findings are extremely valuable in that they provide understandings of how science instruction can move away from a traditional teacher-centered approach to one that is focused on the students as active participants in their own learning.

What these studies have placed less emphasis on however, are the specific strategies that experienced model-based teachers use in whole-class discussions to support specific kinds of conceptual learning processes. Harris, et al (2012) found that teachers using techniques similar to the dialogical strategies listed above "could readily elicit ideas and questions but experienced challenges in helping students develop them.", while Kenyon et al. (2011) advocate that, "teachers must incorporate discussions of models and modeling to help students develop an improved understanding (of how science works)"; however they do not offer specific suggestions as to how that should be done.

The present study builds on several of our previous studies in order to speak to this challenge. In a recent study (Williams & Clement, 2015) we identified and described a set of *Cognitive Model Construction Strategies* that are aimed at promoting model construction and development through whole-class discussions. These strategies consist of teacher questions and comments that respond to specific strengths and weaknesses in the ideas being expressed by students. The strategies are intended to support students' reasoning about the domain and support specific steps in the construction and refinement of explanatory models.

We observed that in attempting to foster reasoning, the two veteran high school physics teachers in the case study 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 cycles of 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 Cycle (*Observation, Generation, Evaluation, and Modification*). Existence of these phases had been supported by earlier studies of the model-based teaching of a wide variety and levels of conceptually challenging secondary science topics, from middle school units on human circulation and respiration (Nunez-Oviedo et al., 2008) and atomic theory and particle behavior (Price & Clement, 2014), to high school units on universal gravitation (Stephens & Clement, 2012).

We then analyzed video recordings of student/ teacher dialogue from whole class discussions in these teachers' classrooms in order to look for finer-grained model-based teaching strategies (Williams & Clement, 2015). We converged on a set of fifteen cognitively-focused discussion-based teaching strategies that we refer to as *Cognitive Model Construction Strategies* since they are believed to support students' construction of explanatory models for the science concepts they are studying. Table 1 below sub-divides the fifteen cognitive model construction strategies into the 4 general model construction processes that we refer to above as the OGEM Cycle. We describe the fifteen strategies as *Micro Level* strategies because we view each of them as being a sub-strategy for one of the *Macro Level* OGEM processes.

Macro Level – OBSERVATION	
Micro Level Strategies	***Classroom Transcript Examples***
Requests or provides 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?
Requests or provides diagram to help students recall results of an experiment	T: You had a compass under this wire (draws circuit), 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 new detail or elaboration of the model	T: What happens to charge when it gets to the bulb?
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 these wires?
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?
Requests or provides spatial direction of effect	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?

Macro Level - MODEL EVALUATION	
Micro Level Strategies	***Classroom Transcript Examples***
Requests or provides evidence to support or refute a model	T: She thinks that the top bulb (in this model) 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 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 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 a discrepant question or discrepant event	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: Can anybody think of a way to make the model better –to account for the finding that not all bulbs light with the same brightness?
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 term s of their effects on other elements in the circuit.
Requests or provides differentiation between elements of models.	T: That's probably true. But *is heat the same as charge*?
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
(adapted from Williams & Clement, 2015)

The Next Generation Science Standards (2013) have highlighted the importance of models and modeling cycles. However, those Standards are necessarily painted with a broad brush and teachers are seeking details about how to implement modeling cycles with student participation. The 15 Cognitive Model Construction Strategies are intended to provide such detail. While the examples of the strategies provided in the table originated from observations of the teaching and learning of circuit electricity in high school physics classes (Williams & Clement, 2015), we have observed that the teaching strategies identified are general enough to have utility across other science topic areas and grade levels as well (Nunez-Oviedo & Clement, 2003).

Study Context and Design

The research identifying and categorizing the model-based teaching strategies in Table 1 led us to the question of whether they could be included in pre-service science teacher education. We saw an opportunity to develop a course that had as one of its central foci the exploration of the theoretical principles and practical applications of whole class discussions strategies in the construction of explanatory scientific models. We report here on our initial attempt to do this in an eight-week instructional unit for pre-service secondary science educators.
While our ultimate goal is to have a positive effect on teaching practice, our purpose in this initial exploratory study was more modest: to examine whether the activities of that instructional unit had an impact on the beliefs and practices of the participants regarding the use of whole-class discussion strategies in fostering students' construction of explanatory models.

Our specific research questions were: What is the impact of an eight week (32 contact hour) instructional unit on model-based teaching on pre-service secondary science teachers' 1) beliefs and attitudes about the use of whole-class discussion strategies to support students' engagement in the construction of explanatory models for abstract science concepts, and on their 2) abilities to implement and recognize both Dialogical and Cognitive Model Construction strategies in their own pre-service micro-teaching practice?

Intervention

The instructional unit, which was taken by 17 students (9 females and 8 males) in the one-year post-baccalaureate B.Ed. program at a small liberal arts university in Canada, consisted of 16 two hour classes over an 8 week semester. It employed the following components:

1) The instructional unit began by introducing the future science educators to a series of articles on model-based teaching and learning in science (Clement, 2008; Krajcik & Merritt, 2012; Schwarz et al., 2009; Vosniadou, 2002; Windschitl et al., 2008; Windschitl, n.d.). These papers address such issues as: 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.

2) The pre-service teachers were also introduced to a series of articles on the use of whole class discussions in science teaching (Chin, 2007; Hogan, 1999; Lehesvuori et al., 2013; vanZee & Minstrell, 1997). These papers describe practices that science teachers use to consider students'

initial pre-conceptions about topics, defer immediate evaluation of the correctness of students' ideas, and place responsibility on students to contribute their ideas to the conversation.

3) After an introduction to general discussion stimulating strategies, we introduced the students to the OGEM cycle and the notion of guiding students through these 4 phases of the model construction process. Once the pre-service teachers gained a broad understanding of these macro-level modelling strategies, they were introduced to the separate set of fifteen Cognitive Model Construction Strategies (Williams & Clement, 2015) identified through our analyses of experienced model-based teachers (Table 1). They watched video segments of the experienced model-based science teachers who participated in our previous studies. Transcripts 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 in the videos were utilizing to engage their students in the construction of explanatory models.

4) Next, diagrammatic representations that we developed for these classroom discussions (Williams & Clement, 2015) were shared with the class 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 (15 Cognitive Model Construction Strategies) levels described above.

5) Next, the students were asked to try out the discussion leading strategies 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 and revision of explanatory models for a key concept of the lesson. Some of the topics they chose were: the human circulatory system, sound and light waves, ecological footprints, and chemical reactions; all conceptually abstract subjects that lend themselves well to this type of instruction.

6) One type of feedback that has been shown to impact student learning is that of peer evaluation (Airasian et al., 2012; Guskey, 2009). As such, the in-class mini-lessons were video recorded and copies were provided to the presenting pair and their classmates. Within a week of their micro-teaching presentations, the pre-service teachers received independent written feedback from four of their colleagues, who each had an opportunity to critically review the video recording of the lesson. Using a checklist co-operatively developed in class (refer to Appendix), the peer evaluators identified teaching strategies that their colleagues had employed or not employed in their mini-lessons, including citing examples of particular strategies they had used. Part A of the checklist focused on general classroom practices such as teacher verbal clarity and audibility, the teachers' awareness of student engagement and understanding, and provision of differentiated learning opportunities.

Part B of the checklist provided an opportunity for the peer evaluators to note general discussion-leading strategies that their colleagues had employed in their mini-lessons. These are the kinds of techniques described in the introduction that van Zee and Minstrell (1997), Hammer (1995), Hogan and Pressley (1997), and Chin (2007) have previously identified for use in whole-class discussions in order to promote student engagement and communication. (Refer to Appendix)

In Part C of the checklist, peer evaluators were asked to identify whether the presenters had utilized any of the fifteen Cognitive Model Construction Strategies that they had been introduced to in the unit. These strategies differ from those in Part B of the checklist in that they are intended not just for promoting student participation in scientific discussion, but for promoting conceptual understanding through model construction. 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.

Data Collection, Analysis & Results

Informal Assessment of Students' Engagement in Class

As with the pre-service teachers' mini-lessons, we also video recorded all classroom sessions during the first four weeks of the unit while the students were learning about model based teaching and whole class discussion leading through the various activities described above. These recordings, as well as daily observer notes taken by a visiting science teacher educator, provided us with an initial informal sense of the pre-service teachers' level of engagement with the ideas and practices we were introducing.

Overall, we were encouraged by the students' levels of participation in the learning activities and by their apparent comprehension of the purposes of, differences between, and implementation of the Dialogical and Cognitive Model Construction strategies. For example, while working in small groups, when asked to match the types of Dialogical and Cognitive Model Construction strategies being used in segments of unfamiliar transcripts with those from a list, the pre-service teachers were able to do so with a 70-80% success rate. Additionally, when asked to present their interpretations of the interplay of Cognitive Macro, Micro, and Dialogical strategies in leading whole class discussions, the emerging educators were able to provide a variety of insightful diagrams and explanations.

Pre-Post Survey

On the first day of the unit, we administered a survey we had developed to assess the pre-service teachers' prior knowledge, beliefs, and attitudes about model-based teaching and whole-class discussions. Previously established survey instruments that were examined (Duschl & Wright, 1989; Luft et al., 2003; Palmquist & Finley, 1997;) did not contain questions of high relevance to the objectives of this unit so we worked to create an instrument that would. One of our purposes in developing this survey was to create and pilot a set of new questions for teachers centering on model-based learning and whole class discussion.

At the end of the eight-week unit, and just before they began their first of two nine-week practice teaching internships in public school classrooms, the students completed the survey again. Comparisons of the pre and post-instruction survey responses of the 17 science education students were done to establish whether any statistically significant differences existed between their responses on the pre and post-instruction surveys.

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. While a copy of the complete survey instrument and notes regarding the coding of student responses is included in the Appendix, statistical analyses determined that the responses to the survey questions highlighted in Table 2 showed significant change 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 discussions in science classes	3.25/4.0	3.82/4.0	+0.57 / 4.0
1e	Rate your opinion of the usefulness of simulations in science classes	3.25/4.0	3.82/4.0	+0.57 / 4.0
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 / 100
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 /100
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 / 4.0
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 / 4.0
3h	Rate your opinion of the importance of focusing students on explanatory models as a purpose for whole class discussions.	3.05/4.0	3.94/4.0	+0.89 / 4.0
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 / 4.0
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 / 4.0

Question Number	Question	Pre-Instruction Survey Avg.	Post-Instruction Survey Avg.	Change
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 / 4.0
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 /4.0

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

Discussion of Survey Results

Statistically significant differences were observed pre to post on a number of the questions, suggesting changes in the students' beliefs and attitudes. They suggest 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. The following are hypotheses as to why some of these changes 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. We assume that the first occurred because the majority of the assigned readings and the video clips of experienced teachers used during the unit focused on the usefulness of whole class discussions to support students' construction of explanatory models for science concepts, and it was gratifying to see a shift here. Also in many of the classroom videos, diagrams and computer generated simulations were utilized as means for fostering student reasoning so this may have influenced the pre-service teachers' opinions.

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, an important and significant change. One likely source of this effect is the strong emphasis during the unit on classroom discussions as a teaching method (e.g. the students read Chin, 2007; Hogan, 1999; Windschitl, n.d.; van Zee & Minstrell, 1997). As is emphasized in the NGSS (2013), it appears as though these 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. The following purposes for whole class discussions gained in support significantly: fostering students' scientific reasoning, having students make predictions, supporting students' generation and evaluation of explanatory models, and engaging students in thought experiments. Although these are science teaching practices that are highlighted in the assigned readings and video exemplars, we suspect they are more sophisticated than those discussed in many teacher preparation courses. One could imagine that students might not comprehend them or might be skeptical about their relevance to teaching, so we found it very interesting that we were able to measure an effect here.

Questions 4 and 5 of the survey addressed 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 unit, they believed that students should contribute 68% of these explanations and teachers only 32%. Similarly, we saw a statistically significant shift from the pre-instruction survey towards increased student participation in the *evaluation of explanatory models*. Here we hypothesize that watching videos of discussions in which students exhibit model based reasoning may have been important in generating the change on this question. These two findings are consistent with the views of Windschitl et al. (2008), Schwarz et al. (2009), Williams (2011), and Krajcik & Merritt (2012) who advocate that students should be at the center of such model construction and revision activities.

Finally, the responses to survey Question 7 indicate that the pre-service secondary science educators 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 engaged and discussed and gradually brought in line with the scientifically accepted target models. This is perhaps the most controversial belief asked about in the survey - that one can start from parts of students' prior knowledge that is incorrect, so we were interested to see a positive change here. 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. Again, it is quite possible that these changes in pre-service teacher thinking were supported by the classroom videos which provided evidence of students starting out with incomplete models that were evaluated and revised over time.

There were also questions on the survey for which the pre-service teachers' responses decreased from pre to post-instruction. For example in Question 3, which polled the emerging teachers' perceptions of the usefulness of whole class discussions in supporting various student learning activities and skills, on average, responses decreased for: reviewing material learned from the textbook, allowing students to ask the teacher for information, and reaching closure on target concepts and correct answers to questions. It is not surprising that support decreased for the first one since this practice was not promoted in the course. It is interesting however that, after the instructional unit, the pre-service teachers put less emphasis on the other activities that might be considered to be of importance. It is hypothesized that this willingness to allow students to grapple with incomplete explanatory models and defer arrival at the target model may have come from reading articles that promoted *postponing* closure via a step-wise evolution of conceptual understanding and watching videos of experienced teachers who guided their students through activities and discussions that fostered conceptual change over time.

In summary, based on the review of video recordings and observer notes describing the students' participation in the unit's instructional activities as well as the statistical analysis of the pre/post-test results, it appears the pre-service science teachers gained an appreciation for the importance of: whole class discussion, centering science instruction on the learner, starting from students' prior knowledge, and engaging them in an evolutionary process of generating, evaluating, and modifying explantory models.

Mini Lesson Peer Evaluations

For the 34 peer evaluation forms that were completed (each of the 17 participating pre-service teachers completed two), a coding system was developed wherein we attempted to determine the degree to which the pre-service teachers: a) utilized certain Dialogical and Cognitive Model Construction strategies in their mini-lessons, and b) were able to recognize these strategies being used in the lessons of their peers. Through analysis of the video recordings of the eight 40 minute mini lessons, the first author and a second researcher independently coded and established the number of times each of the 15 Dialogical and 15 Cognitive Model Construction strategies were utilized. We then counted the number of times students were able to identify these Dialogical and Cognitive Model Construction Strategies being used in the mini-lessons of their classmates by noting their mention on the Peer Evaluation Checklists. The rate of inter-rater agreement between the two coders was found to be 86% on identifying students' use of strategies in the mini-lesson videos and 94% on identifying students' recognition of their classmates' use of these strategies in peer reviews of their mini-lessons. In order to establish final values for these counts, the two coders reviewed sections of videos, transcripts, and peer evaluations together in order to come to agreement on any coding discrepancies.

Since each mini-lesson video was peer evaluated by 4 independent pre-service teachers, in a perfect situation where all 4 consistently identified every strategy being used, there should be 4 times as many "peer identified instances" as there are "researcher identified instances". Subsequently, in an effort to determine the overall accuracy of the students' strategy identification efforts, the number of correct "peer identified instances" was divided by the number of "researcher identified instances X 4" and the result was expressed as a percentage. The results of these observations and calculations is shown in Tables 3A and 3B below.

Dialogical Discussion Leading Strategies

Strategy Used	Researcher Identified Instances	Peer Identified Instances	Peer Identification Accuracy
Establish a safe environment	26	87	84%
Raise a key question	13	40	77%
Adjust the question	6	17	71%
Withhold answers	9	25	69%
Defer judgment	16	49	77%
Appreciate student contributions	43	142	83%
Provide Wait/ Think Time	37	112	76%
Ask Low Cognitive Demand Questions	41	137	84%
Use a traditional I R E Sequence (Ping Pong)	18	55	76%
Probe	44	153	87%
Use a Reflective Toss	9	22	61%
Mark/ Amplify/ Paraphrase	29	99	85%
Encourage Student to Student Talk (Volleyball)	13	44	85%
Scaffold Academic Language	10	31	78%
Voting	5	18	90%
TOTAL	**319**	**1031**	**81%**

Table 3 (Part A) – Student Use and Peer Identification of Dialogical Strategies

Cognitive Model Construction Strategies

Strategy Used	Researcher Identified Instances	Peer Identified Instances	Peer Identification Accuracy
Requests or provides observations	21	67	80%
Requests or provides diagram to help students recall results of experiment	7	26	93%
Requests or provides the initiation of model construction	19	61	80%
Requests or provides a model element to explain specific observation	11	28	64%
Requests or provides spatial direction of effect	5	14	70%
Requests or provides new detail or elaboration of the model	17	53	78%

Strategy Used	**Researcher Identified Instances**	**Peer Identified Instances**	**Peer Identification Accuracy**
Requests or provides an analogy	8	27	84%
Requests or provides evidence to support or refute a model	20	67	84%
Requests or provides the design of an experiment or thought experiment	8	22	69%
Requests or provides running a model for prediction or evaluation	5	12	60%
Requests or provides a discrepant question or discrepant event	9	24	67%
Requests or provides additions or changes to the model	12	37	77%
Requests or provides differentiation between elements of models.	5	14	70%
Requests or provides integration of two models or concepts.	6	14	58%
Requests or provides repair to or refinement of the language describing the model	11	35	80%
TOTAL	**164**	**501**	**76%**

Table 3 (Part B) – Student Use and Peer Identification of Cognitive Model Construction Strategies

The data in these charts indicate that overall, the pre-service science teachers in this study were able to implement Dialogical and Cognitive Model Construction strategies in their mini-lessons, and were able to recognize these strategies being used in the lessons of their peers. The degree to which the emerging science educators utilized the more general Dialogical strategies was approximately two times greater than that of their implementation of the Cognitive Model Construction strategies (319 instances compared to 164 over the 80 mini lessons). A possible factor here is familiarity since the types of discussion-leading strategies in the Dialogical category are likely to be more commonly used by educators the pre-service teachers have observed than those of the Cognitive Model Construction type. Dialogical strategies are used by teachers in a wide range of curricular areas to support whole-class discussions whereas Cognitive Model Construction strategies are specific to the development of conceptual models in science so it is not surprising that the students in this study were able to implement the former more readily than the latter in their first attempts.

It was interesting to observe, however, that the rates at which the pre-service teachers were able to accurately identify the use of both Dialogical and Cognitive Model Construction strategies in the mini-lessons of their peers were quite similar with averages of 81% and 76% respectively. Since most of the students were quite unfamiliar with the process of constructing explanatory scientific models before engaging in the course, it is encouraging to see that after learning about them and observing them being used by veteran teachers, they were able to recognize them in the teaching efforts of their peers.

Excerpts from Student Interviews

At the end of the unit, a focus-group of six participants from the class was established in order to question them about the micro-teaching experience. The students were asked specifically about their attempts to use cognitive model construction strategies in their mini-lessons. They had the following to say:

Jenna: *Yeah, I have to say, that was the hardest part of the discussion-leading process for me. And no offence Meghan, but I don't think we did the best job with that. We did pretty well with the dialogical strategies like using wait time, paraphrasing students' comments, and adjusting our questions when people didn't understand, but I think the cognitive strategies were just harder for us.*

Meghan: *I'll agree with that 100%. I think since this whole model-based way of teaching is pretty much a new thing, even for those of us with science backgrounds, using the cognitive model construction strategies is not something that we have experienced a great deal of. We have all seen the dialogical strategies used in many of our previous classes, even in non-science classes, but the model-based stuff; that's pretty new.*

Brad: *One thing we did to try to make sure we included some of the cognitive strategies in our lesson was to discuss which ones might be useful while we were making up our lesson plan. For example, since our lesson was on chemical bonds, we knew we were presenting some very abstract ideas so we actually kept the list of model construction strategies close by while planning the lesson. Sarah and I were thinking that some strategies like using analogies, getting the students to run their mental models to make predictions, and designing the activities so that students would want to make changes to their models would be important. It's tough with only a 40 minute lesson to expect students to have enough time to really think about their models and make a lot of modifications to them, but we tried.*

Josh: *"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 the students engaged in generating models for that concept and thinking of many different possibilities'. So, it can be confidence building too."*

It is interesting to note that while the pre-service teachers who participated in the focus group interviews felt they understood the usefulness and importance of engaging students in model-based discussions, they admit that knowing exactly how and when to use the cognitive model construction strategies they learned about was a challenge for them. They agreed that these strategies made sense to them and they could *identify* them being used by the expert teachers in the videos they watched, but that being able to *implement* them in their own teaching was something they felt would take practice.

Conclusion

Secondary science topics such as magnetism, electricity, erosion, planetary motion, natural selection, and atomic theory 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*. Analysis of the student/ teacher dialogue from whole class discussions of veteran K-12 science teachers in our previous studies has led us to the identification of what we refer to as *Cognitive Model Construction* teaching strategies intended to support the students' conceptual understanding. We describe these fifteen strategies as *Micro Level* strategies because we view each of them as being a sub-strategy for one of four *Macro Level* OGEM processes (Observation, plus model Generation, Evaluation, and Modification).

Based on these findings, we developed and implemented an eight-week instructional unit for pre-service secondary science educators in the one-year post-baccalaureate B.Ed. program at one of our institutions. We view discussion leading for model based learning, especially with cognitive strategies, as a complex skill, making this an ambitious challenge. Consequently, the instructional unit was designed to develop our students' knowledge, beliefs and attitudes about model-based whole-class discussions and employed a variety of learning activities such as (1) journal article reviews, (2) classroom videotape observations, (3) teacher/ student dialogue transcript analyses, (4) teacher strategy identification exercises, (5) classroom discourse diagramming examples, and (6) peer evaluations of video recorded micro-teaching sessions.

With respect to the first research question posed in the study: 1) What is the impact of an eight week (32 contact hour) instructional unit on model-based teaching on pre-service secondary science teachers' beliefs and attitudes about the use of whole-class discussion strategies to support students' engagement in the construction of explanatory models for abstract science concepts? Through the analysis of pre and post-instruction surveys, we note that the pre-service science teachers appear to have gained an increased appreciation for (1) utilizing whole class discussions to support student reasoning, (2) centering science instruction on the learner, (3) starting from students' prior knowledge, and (4) engaging them in an evolutionary process of generating, evaluating, and modifying explantory models to help them better understand abstract science concepts and phenomena.

Although our study is exploratory, the results provide an initial existence demonstration that a course that takes whole-class discussion and modeling strategies seriously can positively influence the beliefs of pre-service students about important aspects of pedagogy. This shift in the pre-service teachers' thinking about how best to structure science instruction aligns with Next Generation Science Standards' goal of integrating the teaching of core ideas and scientific practices.

Regarding the study's second research question: 2) What is the impact of an eight week (32 contact hour) instructional unit on model-based teaching on pre-service secondary science teachers' abilities to implement and recognize both Dialogical and Cognitive Model Construction strategies in their own pre-service teaching practice?

As shown in Tables 3A & B, in their micro teaching, the students collectively as a whole were able to implement all of the dialogical and cognitive strategies identified. In the peer evaluations of micro-teaching most of the pre-service teachers were able to recognize Dialogical and Cognitive Model Construction strategies in the mini-lessons of their peers with averages of 81% and 76% accuracy, respectively. We believe this provides some hope that these types of teaching strategies can be identified, described, explained, learned, and implemented in micro teaching. This result provides encouragement for our continuing efforts to improve the course and its emphasis on Dialogical and Cognitive strategies. However, it should be noted that a substantial portion of 8 weeks of classes was spent on these strategies in this course, and our impression is that this kind of time allocation for these topics would require additional time or a shift in priorities in most science teacher education programs. An important question for future research is whether this amount of time could be compressed while still retaining some of the gains measured.

Through the implementation of a post-instruction focus group process, we determined that the pre-service teachers felt planning and facilitating their own discussion-centered model-based mini lessons as well as participating in peer evaluations of those lessons contributed to changes in their beliefs and attitudes about using whole-class discussions to support students' construction of explanatory models. The pre-service science teachers who were interviewed indicated that this process gave them significant insight to the effectiveness of using class discussions to foster the construction and revision of explanatory models for conceptually challenging topics.

This exploratory study reports on an attempt to design and evaluate a course that makes a serious attempt to develop whole class, model-based discussion strategies that we have observed in expert teachers. It is important to note that, as such, the study is limited by the small number of course participants and the singularity of the trial. Therefore, it would be desireable to conduct the pre and post-instruction survey with other groups of pre-service secondary science teachers participating in the instructional unit to determine whether the results are consistent with our initial group. While we did see evidence of strategy implementation during the micro-teaching sessions for the initial group, it would be very interesting to monitor the classroom practices of preservice teachers during their teaching internships to determine whether any changes in beliefs about model-based whole class discussions lead to continued implementation of model-based discussion-centered teaching strategies. Our expectation is that follow-up support will be needed for many teachers to continue to develop strong discussion leading skills within the many distractions of real-life classrooms. We believe this may be especially true for the implementation of Cognitive Model Construction strategies since this is a pedagogical approach that challenges science teachers to engage students in a cooperative process of generating, evaluating and modifying explanatory models; something that most did not experience in their own science learning.

By utilizing a newly identified set of cognitive strategies for whole-class discussion leading that are divided into macro and micro levels (plus an additional dialogical support level), we have attempted to aid the work of teachers and teacher educators by dividing the extremely complex act of discussion leading into several basic sets of learnable skills. By providing opportunities for teachers to learn, practice, and implement these strategies into their practice and through the process of peer evaluation, we are optimistic that science educators can discover the benefits of engaging their students in discussions to support the construction and refinement of explanatory models.

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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 Experiments	
b. Small Group Discussions	
c. Whole Class Discussions	
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 discussions	
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 Purposes for Whole Class Discussions	**Rate Your Opinion**
a) Reviewing correct knowledge that students have already been introduced to	
b) Uncovering student ideas, no matter how incorrect	
c) Providing diagnostic information for the teacher	
d) Allowing students to ask the teacher for information	
e) Fostering scientific reasoning	
f) Reviewing material learned from the textbook	
g) Having students make predictions	
h) Focusing students on explanatory models	
i) Having students generate explanatory models	
j) Reaching closure on target concepts and correct answers to questions	
k) Revising students' ideas to become less incorrect	
l) Engaging students in thought experiments	
m) Allowing students to evaluate explanatory models	
n) 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 discussions, "correct" models can be constructed from earlier student models that are incorrect in significant ways?

Completely agree	
Somewhat agree	
Somewhat disagree	
Completely disagree	

Notes regarding coding of student responses:

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.

Example of a Student's Response to the Science Mini-Lesson Peer Evaluation Checklist – Part B

Dialogical Discussion Leading Strategies

Strategy Used	**Evaluative Comments on Peer's Teaching**
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?" Joanna: "Remember to look outside of just animals too."
Withhold answers	No answers were withheld.
Defer judgment	In the example below at 23:00 minutes in "Appreciating student contributions" Joanna 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". Joanna: "Can you explain to the class what a metamorphic life cycle is?" Ben explains… Joanna: "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, Joanna 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: Joanna: “What is the difference between vertebrates and invertebrates?” Mark: “They have a vertebrae”. Joanna: “And what’s a vertebrae?” Mark: “A spinal cord”. Joanna: “Yes, exactly.” 16:25: Joanna: “Who can give me some examples of animals that are invertebrates?” Students: “Sea cucumbers” “Jellyfish”… Joanna: “Yes, exactly”.
Probe	Joanna: “Why do we classify organisms?” Allison: “To find similarities between animals.” Joanna: “Why do we want to do that?” 19:00: Joanna: “Can you maybe go into a little bit more detail and explain this to the class?” after Corey 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”. Joanna: “Why do they have fur?” Student: “To regulate temperature and keep warm.” Joanna: “And what could you build off of that?” Great sequence of reflective tosses! 16:20: Joanna: “What is the difference between vertebrates and invertebrates?” Mark: “They have a vertebrae”. Joanna: “And what’s a vertebrae?”
Mark/ Amplify/ Paraphrase	16:20: Joanna: “And why again are they considered invertebrates?” Students: “Because they don’t have a backbone”. Joanna: “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?” Allison: “Birds” “Reptiles” “Amphibians” “Fish” …. Sarah: “Yes!”
Scaffold Academic Language	19:15: Joanna: “So what might be a simpler term that we can use to describe this?” … “Warm-blooded, great!”
Voting	31:00: Joanna: “Everyone raise your hand if you think that webbed feet belong in the amphibians group […] Great, that seems to be the class consensus!”

Example of a Student's Response to the Science Mini-Lesson Peer Evaluation Checklist – Part C

Cognitive Model Construction Strategies

Macro Level	Micro Strategy Used	Comments
Observation	Requests or provides observations	You requested 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: Carley: "Birds have wings and can fly". Joanna: "But do all birds fly?" Class: "No". Joanna: "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.

Macro Level	Micro Strategy Used	Comments
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	This strategy did not appear to be used

	Requests or provides new detail or elaboration of the model	Joanna: "Why do they have fur?" Student: "To regulate temperature and keep warm." Joanna: "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.
Evaluation	Requests or provides 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
	Requests or provides a discrepant question or discrepant event	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 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 or provides integration of two models or concepts.	This strategy did not appear to be used
	Requests or provides repair to or refinement of the language describing the model	19:15: Joanna: "So what might be a simpler term that we can use to describe this?" … "Warm-blooded, great!"