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Teacher Challenges, Perceptions, and Use of Science Models in Middle School Classrooms about Climate, Weather, and Energy Concepts

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TEACHER CHALLENGES, PERCEPTIONS, AND USE OF SCIENCE MODELS IN MIDDLE SCHOOL CLASSROOMS ABOUT CLIMATE, WEATHER, AND ENERGY CONCEPTS

by

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CERTIFICATE OF APPROVAL

PH.D. THESIS

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ABSTRACT

Research suggests that scientific models and modeling should be topics covered in K-12 classrooms as part of a comprehensive science curriculum. It is especially important when talking about topics in weather and climate, where computer and forecast models are the center of attention. There are several approaches to model-based inquiry, but it can be argued, theoretically, that science models can be effectively implemented into any approach to inquiry if they are utilized appropriately. Yet, it remains to be explored how science models are actually implemented in classrooms. This study qualitatively looks at three middle school science teachers' use of science models with various approaches to inquiry during their weather and climate units. Results indicate that the teacher who used the most elements of inquiry used models in a way that aligned best with the theoretical framework than the teachers who used fewer elements of inquiry. The theoretical framework compares an approach to argument-based inquiry to model-based inquiry, which argues that the approaches are essentially identical, so teachers who use inquiry should be able to apply model-based inquiry using the same approach. However, none of the teachers in this study had a complete understanding of the role models play in authentic science inquiry, therefore students were not explicitly exposed to the ideas that models can be used to make predictions about, and are representations of, a natural phenomenon. Rather, models were explicitly used to explain concepts to students or have students explain concepts to the teacher or to each other. Additionally, models were used as a focal point for conversation between students, usually as they were creating, modifying, or using models. Teachers were not observed asking students to evaluate models. Since science models are an important aspect of understanding science, it is important that teachers not only know how to implement models into an inquiry environment, but also understand the characteristics of science models so that they can explicitly teach the concept of modeling to students. This study suggests that better pre-

service and in-service teacher education is needed to prepare students to teach about science models effectively.

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CHAPTER ONE: INTRODUCTION

The use of science models is common practice throughout the scientific community; however, models are most predominately experienced by the general public by way of weather and climate forecasting. Although familiar with weather forecasts on television and the Internet, most people do not understand the process of using computer models to generate weather and climate forecasts. As a result, the public often misunderstands claims scientists make about their daily weather as well as the state of climate change. Since computer models are the best method we have to forecast the future of our climate, the weather, and all complex scientific phenomenon (de la Rubia & Yip, 2008), scientific models and modeling should be a topic covered in K-12 classrooms as part of a comprehensive science curriculum (Grosslight, Unger, Jay, & Smith, 1991; Harrison & Treagust, 2000; Justi & Gilbert, 2002; Michaels, Shouse & Schweingruber, 2008; NCISLAMS, 2000; NRC, 1996; Schwarz et al., 2009). According to the National Science Education Standards, teachers are encouraged to teach about science models as a way to aid in the understanding of the nature of science (NRC, 1996; 2012). However, there is very little description of what constitutes a science model, so the term is often associated with scale models. Therefore, teachers often use drawings or scale representations of physical entities, such as DNA, the solar system, or bacteria. In other words, models used in classrooms are often used as visual representations, but the purpose of science models is often overlooked.

The purpose of this research study is to describe the strategies teachers use to engage students in talk about student-created science models, in order to help students learn about science content as well as the concept of science modeling. There has been some previous research studies published that look at the benefits of incorporating science models into the classroom, including strategies and specific curriculum designs (Acher et al., 2007; Henze, van Driel & Verloop, 2007; Justi, 2002; Schwarz & White, 2005; Schwarz et al., 2009). However, there have been very few studies that explore how teachers may implement student use of models without a specific set of curriculum. As a result, there is need for a study that describes how teachers use the approach so that there can be more effective support for science teachers to 1) implement science models effectively in the classroom and 2) engage students in useful dialogue about science content.

Inquiry

Inquiry is a recommended approach to teaching science content that involves students taking part in the scientific processes of generating questions, designing experiments, gathering evidence and making claims about science concepts (AAAS, 1993; NRC, 1996). There are many ways to incorporate inquiry into the science classroom, however my research will focus on an approach to model-based inquiry.

The most general description of an approach to inquiry is highlighted in the Next Generation Science Standards (NRC, 2012) and is referred to as the five essential features of inquiry. The 5E model is another general approach to inquiry, with five elements that guide teachers to support learners throughout the process. Each feature of the five essential features and 5E approaches will be discussed in detail in Chapter Two, however it should be noted that each feature of both approaches is evident in each of the popular approaches to inquiry discussed in this framework and will be considered in the approach to model-based inquiry used in this study.

Another common approach to classroom inquiry is argument-based inquiry. There have been numerous studies on the use of argument to help students construct scientific knowledge (Driver & Oldham, 1986; Driver, Newton & Osborne, 2000; Duschl & Osborne, 2002; Hand, Norton-Meier, Staker & Bintz, 2009; Keys, Hand, Prain & Collins, 1999; Osborne, Ersuran & Simon, 2004; Posner, Strike, Hewson & Gertzog, 1982). The purpose of argument-based inquiry approaches is to emphasize the communication element of inquiry, as described by the NRC (1996; 2012); however specific approaches, such as the Science Writing Heuristic (SWH) can also include the other elements as well (Hand et al., 2009; Keys et al., 1999). The SWH approach has a more specific framework than the five essential features and the 5E approach, which will be discussed further in Chapter Two. Like the SWH, the approach to model-based inquiry used in this study will be more specific and less general.

Model-Based Inquiry

Model-based inquiry is often defined as students learning about concepts through explicit use of scientific models; this means the students create, critique, and modify models. This approach is different from how model use is most commonly perceived in the classroom, which involves the use of pre-constructed models from textbooks or teaching kits (Schwarz et al., 2009; Edelson, 2001). Recent research indicates that students who create their own scientific models have better understanding of a concept than students who use pre-constructed models because it allows them to visualize 1) *how* and *why* the model works as a representation of the natural phenomenon and 2) the predictive power of models (Edelson, 2001; Henze et al., 2007).

For the purpose of this approach to model-based inquiry, a model is defined as a *representation that focuses on key features to explain and predict a scientific phenomenon* (Schwarz et al., 2009). Based on this definition, just about every science concept is actually a type of model. Some examples include Bohr's model of the atom, DNA's double helix structure, the behavior of photon and wavelength energy, and the theory of relativity (NCISLAMS, 2000). Although these kinds of models may seem different than computer models, such as climate and weather forecast models, they are actually the same thing because we can use all these models to represent and explain a natural phenomenon as well as predict outcomes (de la Rubia & Yip, 2008). In other words, a *science model* is essentially what science education often refers to as a *scientific theory*, with the exception that the focus of models in the science classroom is on the representation; in authentic science, the focus is on explanation and prediction of the natural phenomenon. Regardless, both science theories and models are essentially claims about a phenomenon that are well supported with evidence we observe from nature. In my research project, I hope to clarify that it is important to emphasize all three elements of science models in the classroom (representation, explanation, and prediction) in order to expose students to both authentic science as well as effective visualization of a science concept.

Generally, the predictive power and limitations of models is not emphasized in the science classroom. Therefore, it makes sense that outcomes of atmospheric forecast models are not clearly understood by the general public. Without exposure to the concept of modeling, students may never come to understand that the evidence for these claims lies within the science model itself. Hence, we cannot expect students to understand, let alone reason about, scientific claims- such as the future of our climate.

Purpose of the Study

The purpose of this study is to identify how teachers currently use science models to teach about climate, weather, and energy topics in the middle school classroom; with a specific focus on the role those models play in the process of inquiry. Additionally, this study aims to describe how teachers perceive themselves using models and how they perceive models could be used, particularly within an inquiry setting. Findings about how teachers use models will be compared to a summary of literature describing how models should be used in the classroom in order to see how well the actual classroom use overlaps with the theoretical use of models. The goal is not to identify faults in the teachers' approaches to model-based inquiry, rather it is to identify where model use is difficult for teachers and what limitations exist for teachers to use them in accordance with the theory described in the literature. The ultimate goal is to provide insight as to what teachers need to know about models and/or inquiry in order to use model-based inquiry effectively as well as how realistic the theoretical approaches to model-based inquiry is for use in actual classrooms.

Research Questions

There are three research questions that guide this study. The overarching purpose is to explore how teachers use science models to foster dialogue among students in their classrooms, but specifically, the following issues will be addressed:

1. What are teachers' perceptions of how the use of models support student learning in the science classroom?
2. How do teachers use models to support student learning in the science classroom
    a. In terms of the type of models used?
    b. In terms of inquiry approaches (questions, claims, evidence, evaluation, prediction)?
    c. In terms of elements of dialogue (idea exchange, interactions, conversation patterns)?
3. What challenges do teachers have implementing science models as a means to help students understand science concepts, the nature of science models, and evidence-based ideas?

Significance of the Study

As discussed in the previous section, there are contributions to the body of knowledge about model-based inquiry. However, the majority of the research so far has been theoretical, such as defining science models (Gilbert, Boulter & Elmer, 2000; Harrison & Treagust, 1998; 2000; Michaels et al., 2008; NCISLAMS, 2000), emphasizing the role models play in science (NRC, 1996; Schwarz et al., 2009; Stewart, Cartier, & Passmore, 2005; Windschitl, Thompson, & Braaten, 2008; Harrison & Treagust, 2000; Treagust, Chittleborough, & Mamiala, 2002), and a few studies look at students' and teachers' understanding of models (Henze et al., 2007; Edelson, 2001; Schwarz et al., 2009; Windschitl et al., 2008). Previous literature also indicates that dialogue between students about science concepts is an effective way to build both reasoning skills as well as understanding of the concept (Driver & Oldham, 1986; Driver et al., 2000; Duschl & Osborne, 2002; Hand et al., 2009; Keys et al., 1999; Osborne et al., 2004; Posner et al., 1982). Therefore, it is important to describe how effective the use of science models is at helping teachers foster dialogue between students as they discuss science content.

There have been very few studies that look at how model-based inquiry plays out in classrooms, focusing on how teachers go about implementing models into their classroom without the use of a specific curriculum. Since the implementation of science models as an inquiry approach is a relatively new idea for the field of science education, it is important to describe how teachers use the approach in their classrooms. Good description of the strategies teachers use can provide the community with a better understanding of both the teachers understanding of the concept as well as their ideas about how effective it is for student learning.

Additionally, it is important to consider how teachers perceive models and how they use them within their own, individual approaches to inquiry. This is especially important when you consider the fact that administrative policies vary between districts, and even schools, which may limit teachers from using a specified model-based inquiry curriculum. However, if teachers can incorporate models in a way that aligns with whatever approach to inquiry that they already use, it makes the use of model-based inquiry more accessible, and thus more likely to occur. That's why, in order to evaluate the effectiveness of using student-constructed science models in the classroom, it is important to describe the challenges teachers face when implementing such an approach.

With understanding of teacher challenges, we can improve upon our techniques to help prepare teachers to use science models effectively in their classrooms. This is especially important now, with the release of the Next Generation Science Standards, which suggests that students should have a conceptual understanding of what science models are and the role they play in authentic science inquiry.

Summary

There are five chapters to this dissertation that will provide the details of this study. This chapter provided an introduction to this dissertation, highlighting key ideas from literature that supports the significance of and need for this study. The framework used to set up the methods for this research project is based on the use of models and inquiry approaches in middle school classrooms, so a brief overview of the previous work done regarding science models and inquiry was discussed. Finally, the research questions that drive this study were introduced.

Chapter Two discusses relevant literature that describes how students learn, the various approaches to inquiry, and the role science models play in authentic science as well as in the science classroom. The literature and prior research done will serve to develop framework that demonstrates an approach to model-based inquiry. Chapter Three provides a detailed description of the methodology used to choose participants, gather and analyze data, and establish trustworthiness for the study. Chapter Four reports the findings of this study. And finally, Chapter Five summarizes the findings in terms of the recent literature on argumentation, inquiry, and teacher education about science models.

CHAPTER TWO: THEORETICAL FRAMEWORK

In this section, I will review literature on popular approaches to inquiry. In particular, I will focus on an approach to inquiry called model-based inquiry. In addition to the various approaches, I will take some time to discuss the role of dialogue in the science classroom. This is an important aspect of the study because a previous research study suggests that dialogue plays an important role in the implementation of most inquiry practices, which include argumentation as a reform-based teaching practice.

Student Learning

The framework of this study exists within the constructivist theory of learning, which assumes that the learner is responsible for his or her own learning. It has been shown that learning via constructivism is something that is accomplished at every age level, and, in actuality, very young children have already developed ideas about science and nature long before they are formally taught it in a classroom setting (Driver and Oldham 1986). Therefore, learning by transmission of information alone cannot effectively meet the needs of the learner. Posner et al. (1982) outlined a theory of learning that seemingly parallels Kuhn's *Structure for Scientific Revolution* (1970), which would suggest that a learner processes concepts in a similar manner as scientists do when they are developing new scientific knowledge. Posner et al.'s theory of learning incorporates two major ideas, which are important to the approach to inquiry discussed in this dissertation: conceptual growth and conceptual change.

Posner et al.'s “conceptual growth” parallels Khun's “normal science”. For Posner et al., conceptual growth is a process of building on a learner's current conceptual framework. Each learner has his or her own individual concept map based on prior experience. From a research perspective, Kuhn's “normal science” describes the process of researching hypotheses that build further understanding on current scientific models. Posner et al.'s second idea is that of “conceptual change”. Conceptual change is a very uncommon process that involves the learner rejecting an old conceptual framework and rebuilding a new one to replace the old one. In Kuhn's research perspective, this is a “scientific revolution”. Scientific revolutions involve social restructuring of an old scientific model to a new scientific model (for example, rejecting the geocentric solar system for a heliocentric solar system).

Teaching students using a constructivist approach generally requires a significant change in classroom dynamics, such that focus is on helping students develop conceptual change. Generally, teachers focus on teacher-centered issues of how to teach concepts to students, rather than focusing on the student-centered issues of what students need in order to learn a concept. In order to align with Posner et al.’s theory of conceptual change, teachers need to move from a more teacher-centered approach of classroom teaching to a student-centered one. Doing so not only can improve student learning, it can also improve student understanding of the scientific process, because the process of learning science can align well with how authentic science is done. It is for this reason that the National Science Education Standards call for the use of inquiry in the science classroom (NRC, 1996; 2012). Inquiry can be an effective way to teach science content in a way that supports a student-centered approach to learning and aligns with how authentic science is done.

Approaches to Inquiry

Based on the constructivist paradigm to student learning, inquiry is a recommended approach to teaching science content that involves students taking part in the scientific processes of generating questions, designing experiments, gathering evidence and making claims about science concepts (AAAS, 1993; NRC, 1996; 2012). There are many ways to incorporate inquiry into the classroom, but the Next Generation Science Standards (2012) have provided essential features of inquiry that should occur regardless of the approach used. In this dissertation, the focus will be on one particular approach to inquiry, called model-based inquiry, which will be discussed in more detail later on in this chapter. First, other popular approaches to inquiry will be briefly discussed, which will include the five essential features, argument-based inquiry, and the 5E model.

The Five Essential Features of Inquiry

The National Science Education Standards have been emphasizing the use of inquiry, therefore this work will be heavily based on the standard's five essential features of inquiry, which are:

- Engage students with scientifically oriented questions.
- Students use evidence to develop and evaluate explanations from these questions.
- Students formulate explanations from the evidence.
- Students evaluate their explanations in light of alternative explanations.
- Students communicate their explanations (NRC, 1996; 2012).

Classroom dialogue plays an important role in achieving each of these elements of inquiry. Four of the five elements involve students developing and evaluating explanations about a scientific claim, indicating that students should be expected to communicate their ideas to themselves, each other, or the teacher. One element in particular explicitly states that students should communicate their explanations. Therefore, it is important that teachers are giving students plenty of opportunities to share their ideas with each other and the teacher as a part of the inquiry process.

The elements of dialogue discussed in the prior research (as outlined in Table 2-1), align with the five essential features of inquiry. When engaging students in scientific inquiry, the complexity of the question asked is one way to move dialogue forward, such as "why" or "how". Evidence-based ideas and the depth of idea exchanges between students is important when students are formulating explanations based on evidence, evaluating explanations, and communicating their results. Looking at classroom interactions and conversational Patterns can assess overall classroom dialogue.

Argument-Based Inquiry

There have been numerous studies on the use of argument to help students construct scientific knowledge (Driver & Oldham, 1986; Driver et al., 2000; Duschl & Osborne, 2002; Hand et al., 2009; Keys et al., 1999; Osborne, Erduran, & Simon, 2004; Posner et al., 1982). Argumentation is considered to be a discourse process (Osborne et al., 2004) that is about evaluating and critiquing the construction of scientific claims (Duschl, Schweingruber, & Shouse, 2007). According to Fischer (1995), authentic science is a socially constructed knowledge base centered upon argumentation. No individual scientist can exist without a community of other scientists in which to share ideas, critique ideas, and construct a better understanding of the world around us. In essence, science is based entirely on the process of sharing, critiquing, and constructing knowledge (Fischer, 1995; Kuhn, 1992; Lemke, 1990). The purpose of argument-based inquiry approaches is to emphasize the communication element of inquiry, as described by the NRC (1996); however specific approaches, such as the Science Writing Heuristic (SWH) can also include the other elements as well (Hand et al., 2009; Keys et al., 1999).

Science Writing Heuristic

Although there are a number of ways to implement argument-based inquiry into the science classroom, I will be focusing on one particular approach called the Science Writing Heuristic (Hand et al., 2009; Keys et al., 1999). The SWH, along with most argument-based inquiry approaches can provide a learning environment that allows students to share their ideas without being labeled ”right” or “wrong”. Students design their own investigations by asking questions, proposing methods to address those questions, and carrying out appropriate investigations.

The SWH approach is designed to promote classroom discussions during which students' personal explanations and observations are tested against the perceptions and contributions of other students in the class. Students are encouraged to make explicit and defensible connections between questions, observations, data, claims, and evidence. Students negotiate their ideas with each other during every step of the inquiry process, which is highlighted most clearly in the Science Writing Heuristic (Hand et al., 2009; Keys et al., 1999). In the SWH, the students continually negotiate with their peers through discussion about how to test questions, what evidence they gathered and what claims can be made. In addition, students share their evidence with their classmates and receive critique that allows them to compare their ideas with others, and later reflect on what they learned (Hand et al., 2009). As a result, it is very important that students be able to have an open dialogue for argument-based inquiry practices to be effective, which is a difficult process that takes time and skill (Driver et al., 2000; Duschl & Osborne, 2002; Yore & Treagust, 2006).

A Prior Study on Dialogue and the SWH Approach

In a previous research project (Benus, Yarker, Hand & Norton-Meier, 2013), dialogue was found to be an important factor in the implementation of the SWH approach. Data for the study came from eight K-5 teachers with classrooms identified as having segments that contained small groups presenting claim and evidence about a topic they had been exploring to the rest of the class. Analysis was done on the whole-class talk that occurred as the students were asking questions to the group about their claim and evidence. Whole-class discussion about a group's presentation of claim and evidence from each classroom were extracted from the full transcript for detailed analysis. Every segment from every transcript that met the above criteria was used to develop a rubric that describes a progression of dialogue in these classrooms for five specific categories: complexity of question, depth of idea exchange, classroom interactions, evidence-based ideas, and conversation patterns. The development of these categories and their levels was done through qualitative research methods and has been developed based on evidence from the classrooms as well as relevant literature. A description of these categories is provided in Table 2-1.

These categories were developed in order to *describe* the nature of student talk in the classroom during presentation of claim and evidence. This criteria serves the purpose of helping describe what effective student talk looks like in low to high implementation of argument-based inquiry classrooms. We generally find that higher implementation of reform-based teaching approaches, like the SWH, leads to more evidence of Level Three dialogue.

The main findings of this research project are:

- The existence of student talk is not an adequate indicator of good classroom dialogue. It is not that talk is happening; it is the *kind* of talk that makes for effective dialogue.
- Many of the classrooms analyzed in this project fit the Level Two description. The analysis suggests that it is generally easier for teachers to progress from Level One to Level Two dialogue than to progress from Level Two to Level Three dialogue; because there are very few examples of Level Three dialogue from our data set.

According to the literature, listening plays a key role in students' abilities to have dialogue effective for knowledge construction (Haroutunian-Gordon, 2007). In our previous research study, we found that most Level Three criteria occurred when students were critiquing the claim and evidence the group of students was presenting. Without listening, critique cannot occur because the students have not thought about the claim and evidence being presented (Fischer, 1995). In our research we found that classrooms that critiqued did not display a typical Initiate, Respond, Evaluate (IRE) cycle pattern (Wells

& Mejia Arauz, 2006). Often, conversation was very complicated, but it did have a clear flow of

Table 2-1 Criteria for dialogue during whole-class discussion of claims and evidence.[1]

	Level One	Level Two	Level Three
Complexity of Question	In most cases, questions were asked to explain explicit knowledge	In most cases, questions ask students to explain their comprehension of ideas.	In many cases, questions challenged students to explain, reason through, and/or justify
Depth of Idea Exchange	Even if opportunities existed, ideas were rarely discussed beyond initial response.	Ideas were discussed for several turns of talk but were usually limited to comparing/ checking/ understanding some smaller element of the "big idea".	Ideas were discussed over many turns of talk to help understand many elements/viewpoints of the "big idea".
Classroom Interactions	Students did not ask a student to justify reasoning or evidence. Teacher may occasionally ask for justification and/or reasoning.	Occasionally student(s), and often the teacher, asked follow-up responses that required student(s) to justify reasoning or evidence.	Students often, and teacher may or may not as often, ask follow-up responses that required students to justify reasoning or evidence.
Evidence-based Ideas	There is little discussion of the claim/evidence presented.	There is some discussion of the claim/evidence presented.	There is extensive discussion of the claim/evidence presented.
Conversational Pattern	Student conversation not well connected to previous turns of talk, with very short conversations about student ideas. Generally Q&A format.	Student conversation at least occasionally is connected to previous turns of talk. Some medium-length conversation occurs about a student idea.	Student conversation was consistently integrated with previous turns of talk. Lengthy discussions occur about a student idea.

[1] Level Three is a high level of dialogue and Level One is low to no level of dialogue. Table taken from Benus et al., 2013.

ideas. In most cases, the teacher played a critical role in focusing the students on important ideas, generally by asking the group questions like “What do you think about that idea?” Simple questions like this slowed conversation and focused the students to an important idea that often led to critiquing of claims and evidence. This indicates that the teacher plays a key role in fostering student discourse, which is important for effective implementation of argument-based inquiry approaches.

5E Model

The 5E model is an approach designed to assist teachers with the development of inquiry-based lesson plans (Bybee, et al., 2006). The model is a cycle made up of five elements, which can be done in any order: Engagement, Exploration, Explanation, Elaboration, and Evaluation.

According to Bybee et al. (2006), teachers should work to *engage* students in a task as a way to access prior knowledge, promote curiosity, and make connections between past and present learning experiences. Students *explore* the topic through one or more related activities in a way that challenges their current understanding of the concept. *Explanations* should be something the students do, where they demonstrate their understanding of the concept in some way; however it is reasonable that explanations can be given by the teacher or some other authority in order to provide students with needed information about the topic. Teachers should also challenge students’ understanding of the topic through *elaboration*, by exposing them to new experiences so that they may apply their current understanding to a new situation. Lastly, it is important to assess student understanding using various *evaluation* techniques.

Development of the 5E model is grounded in literature from as far back as 1901, from Herbart’s Instructional Model, Dewey’s Instructional Model (1971; originally published in 1910), the Heiss, Obour, and Hoffman Learning Cycle (1950), and the Atkin-Karplus Learning Cycle (1983). The central focus of all these cycles is reflection;

that is, students are asked to reflect on and evaluate ideas and concepts as a part of the learning process because reflection is an important process to aid in learning (Bybee, et al., 2006). The goal of the 5E model is to provide teachers a method of student reflection, by engaging the students, providing students time to explore the concept, explain the concept, elaborate on their ideas about the concept, and evaluate their understanding of the topic.

Reflection is an important part of what makes the 5E model a popular tool for teaching- in addition to the clear, easy to implement structure. Comparing the 5E to the five essential elements of inquiry, reflection seems to be an underlying theme. With the five essential elements, students are encouraged to focus on gathering their own evidence to support claims with evidence. In the process of evaluating evidence to support claims, reflection occurs naturally. Therefore, the 5E and the five elements are quite similar, with the exception that the five elements imply reflection through an explicit concept of claim and evidence.

Model-Based Inquiry

The next inquiry approach that will be discussed is commonly referred to as model-based inquiry, which involves students learning concepts through explicit use of scientific models; this means the students create, critique, and modify models. This approach is different from how model use is most commonly perceived in the classroom, which involves the use of pre-constructed models from textbooks or teaching kits (Schwarz et al., 2009; Edelson, 2001). Recent research indicates that students who create their own scientific models have better understanding of a concept than students who use pre-constructed models because it allows them to visualize 1) *how* and *why* the model works as a representation of the natural phenomenon and 2) the predictive power of models (Edelson, 2001; Henze et al., 2007).

To introduce model-based inquiry, the role models play in science will be discussed, science models will be defined according to literature, and the role models can play in the classroom to align inquiry with scientific practice.

Nature of Models in Science

One of the most difficult aspects of doing science is that the natural word is a complex system. It is impossible to understand the natural world without the use of models to isolate, simplify, or abstract singular processes (Rosenblueth & Wiener, 1945). Doing so also allows scientists to answer questions that cannot be tested through directly observable methods. Historically, theoretical models were the primary tools for this, where problems were logically solved mathematically or using conceptual deduction; models were generally either a physical or symbolic representations of a concept (Rosenblueth & Wiener, 1945). Models are constructed by isolating a single process (for simpler models), or several interconnected processes (for more complex models) and developing a set of terms and variables that represents the process(es) based on the scientists' current understanding. Models are used as an experiment to test questions by being modified slightly to account for new information, and the results that occur provide evidence either in support of or against the modifications of the model. The claims provide the scientific community with a better understanding of how the simplified process works. This is what scientists refer to as making a prediction (Rosenblueth & Wiener, 1945).

In recent years, scientists utilize computing power to construct mathematical models that are more complex because they can include several processes at once, allowing for a slightly more representative model of the natural world, but not still without it's limitations (Oreskes, 2003; Rosenblueth & Wiener, 1945). Models cannot, nor will they ever be, exact representations of the natural world, they will always be simplified, abstract, representations. Therefore, it is unrealistic to expect predictions made by models to be exactly correct (Oreskes, 2003). Although computer models allow for a more detailed representation and explanation for a science concept, they are still used to do science the same way simpler models were used historically. That is, the models are modified to test the outcome of a particular question and the results provide evidence in support of or against the modified model. Again, scientists refer to this process as a prediction (Oreskes, 2003).

Based on how models are used in actual science inquiry, it is important that this process be translated into the science classroom because it is evident that general understanding of the term *prediction* is different from that of the scientific community (Oreskes, 2003). It is also evident that models can vary in complexity and type, which should also be discussed in the science classroom. Therefore, it is important to explore how models can be defined as well as a specific look at the types of models that exist. This will be explored in the following sections.

Defining Science Model

Arguably the most complicated aspect of developing an approach to model-based inquiry is that there is limited consensus among literature about what constitutes a scientific model. Some authors simply limit their definition to a short list of examples, whereas others attempt to make a generalized definition that can incorporate all possible examples of models. In order to develop a definition for the purposes of this study, this section will look at the nature of models within authentic science, how those models are defined within both the science and education communities, and a list of model typologies based on current research.

When defining science models, some authors limit their definition to a short list, such as Bohr's model of the atom, DNA's double helix, photon energy, and wavelength energy (NCISLAMS, 2000). The NRC (Michaels et al., 2008) defines modeling as "construction and testing of representations that are analogous to systems in the real world" (p. 109), expanding the list of examples to include mathematical formulae and data representations such as graphs, diagrams, and maps. A more generalized definition of a science model comes from Gilbert (2011), who defines a model as a "system of objects, symbols, and relationships representing another system in a different medium" (p. 3). These representations can vary from being simple to abstract.

Similarly, work done by Harrison and Treagust (2000) provides a variety of models that range from simple to complex, arguing that the differences between each of these kinds of models are important to consider when introducing models as representations for science phenomena. It is important to note *that a representation is considered to be a depiction of a specific concept that is not directly comparable to the original concept* (NRC, 1996; Schwarz et al., 2009; Stewart et al., 2005; Windschitl et al., 2008; Harrison & Treagust, 2000; Treagust et al., 2002).

In just about every case, the definition of science models is reduced to being about a representation and nothing else. Although models are most certainly representations, in the previous section it was discussed that scientists do not use models simply as a way to represent the natural world. For scientists, the representative nature of models is the least important characteristic of models within the process of authentic science inquiry. Scientists who use models refer to modeling as the "conceptualization of a problem" (p 1), indicating that models are used as a part of the inquiry process and not just as a way to represent a claim or a concept (de la Rubia & Yip, 2008). The use of models in science is more accurately referred to as prediction (Oreskes, 2003; Rosenblueth & Wiener, 1945). If people view models as being nothing more than a representation of a science concept, then they will believe that all science models are "correct" and the final word on a particular concept. When in actuality, just like scientific knowledge, science models are constantly evolving (even changing) and have limitations (de la Rubia & Yip, 2008; Oreskes, 2003; Rosenblueth & Wiener, 1945; Somerville & Hassol, 2011). It is for these reasons that models are most frequently used as a way to generate new questions and make predictions about unexplained and unobserved occurrences in nature (Somerville & Hassol, 2011). Therefore, models are not just representations that explain a science concept. They must also be used to make predictions, which is a very important distinction to make when applying the use of models within the science classroom.

Model Typologies

In general, it is not uncommon for people to think of models as nothing more than simple physical representations, such as globes, model airplanes, and plastic representations of body parts (Gilbert, 2011). However, several studies have generated typologies of models, which go beyond the simple physical representations we often think of seeing within the science classroom.

The simplest and most familiar to many students is the scale model, a scaled representation of some physical object with little emphasis on internal structure and use (Harrison & Treagust, 2000). Students are often familiar with scale models because they are toy-like (Grosslight et al., 1991).

The next level of simple scientific models is representations used for pedagogical purposes, such as balls and sticks representing atoms and molecular bonds. Slightly more complex models than those are pedagogical representations, which are models that “build conceptual knowledge”, such as chemical/mathematical formulae and theoretical models. All these models represent complex, theoretical concepts in a way that is visual and observable (Harrison & Treagust, 2000) and enhances communication of concepts that are not directly observable (Windschitl et al., 2008).

Models that depict multiple concepts and processes are maps, diagrams, tables, concept-process models, and simulations (Harrison & Treagust, 2000), which would also include statistical models. Finally, the most complex kinds of models are personal, such as mental models and synthetic models. This indicates that the most difficult task for students to do is synthesize their own personal understanding of a science concept with that of the scientific community; however, according to conceptual change literature, this is essentially what we ask students to do every day as a process of learning (Driver & Oldham, 1986; Galbraith, 1999; Klein, 1999; Posner et al., 1982). A further discussion of this dilemma will occur in an upcoming section titled “A comparison of argument and model-based inquiry”.

Similarly, Harrison and Treagust (1998) and Gilbert et al. (2000) discuss different categories in which models fall into. These categories range from simple models, such as concrete representations and physical representations, to complex models like multiple concept or process models. All three sources provide a separate category for personal, mental models. A summary of model typology is provided in Table 2-2.

Table 2-2 Summary of model typology as discussed within three sources.

Simple	Harrison & Treagust (1998)	Harrison & Treagust (2000)	Gilbert et al. (2000)
↓	Concrete representations of reality	Scale	Physical
		Pedagogical	
	Abstractions to communicate a theory	Iconic/symbolic	System or event
		Mathematics	
		Theoretical	
	Depicting multiple concepts and/or processes	Maps, diagrams, tables	Process or group of processes
		Concept-process	
		Simulations	
Complex	Personal/private	Mental	Idea

Model-Based Inquiry in Science Education

Since models play such an important role in authentic science, it should not be surprising that researchers are considering how to incorporate the appropriate use of models into the science classroom. The Next Generation Science Standards talk about the importance of students understanding the role models play in authentic science, as well as experience using models within classroom inquiry. They also play a key role in helping learners develop conceptual understanding of concepts. For these reasons, the science education community has developed an approach to inquiry called model-based inquiry, which will be discussed in more detail after this section.

MBI and the Next Generation Science Standards

While science models were mentioned as an important concept for students to learn in the National Science Education Standards (NRC, 1996), the Next Generation Science Standards (NGSS) puts much more emphasis on the importance of teaching about science models (NRC, 2012). The NGSS framework is divided into three dimensions, which are *Scientific and Engineering Practices*, *Crosscutting Concepts*, and *Disciplinary Core Ideas*. Science models are mentioned in both the *Scientific and Engineering Practices* and the *Crosscutting Concepts*, which suggests that understanding science models is necessary for understanding science.

In the *Scientific and Engineering Practices* dimension, it is suggested that students be able to develop and use science models. This is because scientists develop and use science models as a practice of doing science. It is important to emphasize that students should both develop and use models in the classroom, which goes beyond how teachers generally use models in the science classroom (Schwarz et al., 2009; Edelson, 2001). The NGSS suggest that models should not just be used as a tool to explain concepts to students; rather students should actively take part in designing and building their own models and use those models to either explain a concept, but more importantly to make predictions- since that is how scientists use models in practice.

In the *Crosscutting Concepts* dimension, it is suggested that students understand systems and system models. Crosscutting concepts are ideas that should be applied across all science concepts; therefore they should be used to tie together the *Disciplinary Core*

Ideas dimension of the NGSS not just across disciplines, but across age groups as well. Understanding science concepts involves understanding that specific science concepts leads to further understanding about a more complex system. For example, understanding the transition between phases of water (i.e., evaporation, condensation, melting, freezing, etc.) is a small part of a more complex system of the water cycle, which is also a small part of an even more complicated process of what causes weather. Scientists use models to represent these systems, which can grow increasingly complex as more knowledge is obtained. Similarly, students should develop and use system models across disciplines and age groups in a way that is similar to how scientists use them in practice; which is to make predictions about unanswered questions.

Based on the newly released NGSS, it is important for students to come to understand science models as a part of learning science. As discussed above, it is not just a matter of exposing students to models, they must also use models in a way that aligns with how teachers use models in practice. This means students must develop their own models and use them to make predictions about unanswered questions, and students should be doing so in every discipline and at every grade level.

Science Models and Conceptual Understanding

According to Posner et al. (1982), all students come into the classroom with prior knowledge; that is, every student has some idea of a concept, regardless of whether they have had any formal education about the topic or not. Learning occurs when students accept new information into their existing conceptual framework, which is a process of assimilation (Posner et al., 1982). The process of assimilation is the same process that Harrison and Treagust (2000) describe as taking scientific concepts and synthesizing it with their mental models. Naturally, if this is the most difficult thing for students to do, it is reasonable to expect that understanding the "simpler" models will only aid students in being able to assimilate information effectively. Therefore, explicit instruction of science models can help students learn through the process of conceptual growth.

Based on the culmination of literature and for the purposes of this study, science models should have the characteristics of being a representation, but also as a tool for prediction. Therefore, science models can be defined as *representations that explain and predict scientific phenomena* (Schwarz et al., 2009). By this definition, a *science model* is essentially what science education often refers to as a *scientific theory*, with the exception that the focus of models in the science classroom is usually on the representation; whereas in authentic science, the focus is on explanation and prediction of the natural phenomenon. In order to use model-based inquiry appropriately, teachers and students should be oriented towards using models as tools to make predictions, not just as representations to explain a concept. Yet, regardless of whether models are being used in the classroom or within authentic science, both science theories and models are essentially claims about a phenomenon that are well supported with evidence we observe from nature. As a result, if we expect students to understand science theories, they must be able to represent them, explain them, and use them to make predictions- this is the essence of authentic science inquiry. Therefore, students may construct knowledge more effectively if they are given the opportunity to construct and work with *their own* scientific models.

The majority of the literature about scientific models suggests that they are best used to help students understand the nature of science because it can help students recognize the tentative, but stable nature of scientific concepts (Justi & Gilbert, 2002; Lehrer & Schauble, 2004; Schwarz et al., 2009; Stewart et al., 2005). In addition, it is important to consider that science is arguably shifting from a practice based on observable phenomena towards a practice based on theoretical phenomena (de la Rubia & Yip, 2008; Windschitl et al., 2008), especially in the earth and environmental sciences.

Therefore, using models can also provide students with a better understanding of how theory-based phenomena can be scientifically valid.

A Framework for Model-Based Inquiry

The previous section discussing model typologies mentions that the most complex kinds of models are mental models, indicating that the most difficult thing for students to do is synthesize their own personal understanding of a science concept with that of the scientific community. According to literature, the goal of science education should be to orient students' personal conceptual framework towards that of the scientific community (Driver & Oldham, 1986; Galbraith, 1999; Klein, 1999; Posner et al., 1982). Yet, it is an extremely difficult task for students to do (Harrison and Treagust, 2000), plus it can be extremely difficult for a teacher to assess whether the student understands a concept. Therefore, there is a need to help students align their mental models with that of the science community as well as help teachers assess students' individual understanding of science concepts. The goal of model-based inquiry is to achieve these goals by using models to make student thinking visible.

Incorporating models effectively means we should be asking the students to construct, use, and evaluate their own science models, which is an effective way to make thinking visible. Therefore, since science models are essentially science theories; it can be argued that students can make visual representations of their claims. In other words, models, based on science evidence, are claims. For example, this idea can be deduced when we look compare the SWH approach and model-based inquiry. In the SWH a student *claim* is defined as a 1) meaningful explanation of observations (i.e., evidence) and 2) can be used to draw hypotheses for new testable questions (Hand et al., 2009). In most variations of model-based inquiry, a student *model* is defined as 1) a representation that meaningfully explains observations (i.e., evidence) and 2) can be used to predict results for new testable questions (Edelson, 2001; Henze et al., 2007). Therefore, regardless of the terminology, it can be argued that a student claim and student model is actually the same thing. Therefore, the approach to model-based inquiry used in this study is modified from the framework for the SWH (Hand et al., 2009) and is depicted in Figure 2-1.

Summary

This chapter provided an overview of prior work and literature about inquiry approaches and model use. A discussion about several approaches to inquiry, with particular focus on model-based inquiry, emphasizes the need to develop approaches to teaching science that aligns with how authentic science inquiry is done. Since most scientists must use models in order to do science, it is important that models are used appropriately in the science classroom. This chapter argues that students should be developing, using, and testing models in order to understand authentic science inquiry. To summarize, one approach to model-based inquiry as been presented that can satisfy the need to introduce models into the science classroom.

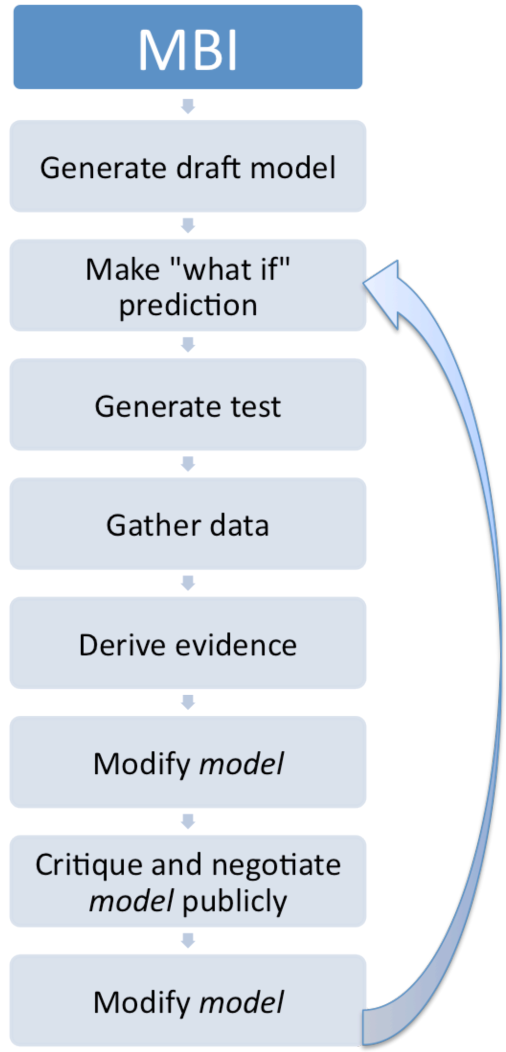

Figure 2-1 Side-by-side comparison of an argument-based inquiry practice with a model-based inquiry practice. Note that student's models are essentially student claims about a science concept. Modified from Hand et al. (2009).

CHAPTER THREE: METHODOLOGY

This chapter will discuss the methods used in the design of this study. First, the details and design of the professional development will be explained, followed by the context of the study, including participant selection. Finally, there will be a discussion of the data collected, analysis procedure, and trustworthiness of the study.

Research Design

The overall design of this research aims to describe how teachers use science models to foster student talk in the classroom. As a result, it is necessary that the teachers involved in this study have some level of exposure to and willingness to implement student-created science models in their classrooms. Therefore, teachers were chosen from a group who participated in a professional development that took place in summer of 2011. Of the twenty-one teachers who attended the professional development, five agreed to participate in the study; however only three of those teachers provided a sufficient amount of data to be included in the study. To answer the three research questions described earlier, interviews and observations were collected and analyzed.

In this chapter, a justification of the research design will be presented, as well as details about the participants, data collection procedures, and data analysis techniques. Additionally, since the participants of my study were purposefully chosen because they participated in a professional development (PD) that oriented them to the proposed inquiry approach, the professional development will also be discussed.

Justification of the Research Design

As a result of participating in the PD, teachers who have agreed to participate in this study taught a unit about climate, weather, or energy that includes the use of science models. To analyze the data, a descriptive case study approach (Merriam, 1998) was used. A descriptive case study is appropriate for this study because the goal is not to make “hypothesized generalizations” (p. 38), rather it is “presenting basic information about an area of education where little research has been conducted” (p. 38). As discussed in Chapter Two, the approach to model-based inquiry that was presented to the teachers focuses on the explicit use of science models without the use of an established, step-by-step curriculum. Currently, there is little research that explores how teachers implement model-based inquiry in their classrooms without the use of a specific curriculum; therefore, a descriptive study is the best way to explore the strategies teachers utilize to implement such an approach.

In addition to the descriptive study methodology, a multiple case-study approach was used to determine data collection and analysis procedures (Creswell, 1998; Lincoln & Guba, 1985; Merriam, 1998). Without a specific curriculum, it makes sense that different teachers will have different strategies to implement the use of science models into the classroom. As a result, having multiple cases to explore in-depth and compare and contrast between not only gives a more detailed description of the use of the approaches they use, but may also allow for more compelling interpretations of underlying themes (Merriam, 1998).

Professional Development

The primary role of the professional development within this study is that it provided a convenient sampling of potential participants. The professional development was designed to expose teachers to content related to climate, weather, and energy topics as well as science models, so those teachers who took part in the workshop had been exposed to some explicit discussion of how to use models in the classroom to teach about science concepts. This section will discuss the details about the design of the professional development.

The opportunity for the professional development (PD) came about as a result of a grant awarded to a professor of Chemical and Biochemical Engineering at the University of Iowa. The initial intent of the professional development was to provide content to high school teachers about climate and energy concepts, with the take-home message for the teachers being that climate is changing and there is consensus among the science community that it is influenced by human activity. After some consideration, the instructors decided to focus on 6-9 grade teachers and include weather concepts because the topics of climate, weather, and energy to be taught aligned best for that age group according to the National Science Education Standards content strands (NRC, 1996; 2012). In addition, the state of Iowa has been working on a set of standards, called Iowa CORE, in which specific earth science content (including weather and climate) is expected to be included into the middle and early high school curriculum (IDOE, 2011).

The PD design was based on empirically tested features of effective PD for science teachers. First, it is important to note that the major focus of the workshop was to provide teachers with content so that they have a firm understanding of climate, weather, and energy concepts while simultaneously providing them with explicit exposure to the concept of science models. It was expected that most teachers probably lacked a firm understanding of the concept of modeling, because they were only familiar with the use of existing pedagogical models and had not considered model development as a form of pedagogy (Justi & Gilbert, 2002). Therefore, the secondary focus of the PD was to have the teachers experience learning science content through the process of model development. The instructors recognized that the second objective would be difficult to accomplish, since recent research suggests that content will be what teachers prefer to get from the PD. Therefore, pedagogical strategies were modeled (AAAS, 1993; Beyer, Delgado, Davis & Krajcik, 2009; NRC, 1996) and explicitly discussed while content was delivered, which was intended to provide the teachers with an adequate foundation in which to build their own pedagogical strategies around the content (Penuel, Yamaguchi, Fishman & Gallagher, 2007).

Second, it is important to provide teachers with plenty of time to actively think about how they will incorporate the new concepts and strategies into their classrooms (Penuel et al., 2007; Penuel et al., 2009). To aid in this process, the instructors provided the teachers with a final project (for credit) to modify an existing unit that they already (or plan to) teach their students about climate, weather, or energy. The requirements of the final project are that it must display 1) understanding that climate/weather concepts are aligned with concepts of energy and can be taught that way in the classroom, and 2) some appropriate use of science models. Teachers worked independently (but in collaboration with other participants) throughout the week on unit concept maps that they presented to the rest of the group on the last day for peer critique and feedback (Penuel et al., 2009). The main purpose of this project was to ensure that the participants left the PD with some clear understanding of how they can incorporate the new concepts into their classrooms.

Thirdly, the instructors wanted to provide the teachers with a few guided activities that they could replicate in their classroom "as is" or with a few alterations. Research suggests that the most effective way to provide these activities to the teachers is by having them perform age-appropriate activities while teaching them the content (Penuel et al., 2009), so that is what was done.

Based on the empirically-tested features of effective PD discussed above, sessions for concept development, pedagogy discussions, and reflection sessions were scheduled throughout the week. Meetings went from Monday through Friday from 8:00am to 5:00pm, with most evenings open for additional project work time. The full week schedule is provided in Appendix A.

In addition to the PD week, research suggests that teachers do better if they have consistent follow-up with the PD leaders, particularly in the form of a follow-up session (Penuel et al., 2009). Therefore, the instructors scheduled a follow-up session with the teachers, which occurred in May of 2012. Teachers participated either in person or by conference call and were asked to discuss successes and challenges they faced when implementing their unit into the classroom. Of the twenty teachers, seven attended the meeting. Each spent approximately ten minutes sharing their units with the rest of the group, followed by a short discussion about the unit between all the participants. In the end, teachers provided feedback to each other, shared helpful documents, and had time to reflect on their units in preparation for next year.

The professional development had two personnel, me and the funding project Principal Investigator, Professor Charles Stanier. The personnel co-instructed the professional development, including the logistical planning, content and assignment development, teaching, and grading. My primary role was to teach a few weather and climate concepts, lead reflective discussions, grade assignments, and act as the logistical "liaison" between the teachers and instructors. In most cases, I took on the role of pedagogical expert while Professor Stanier took on the role of content expert.

Detailed Description of Participants

Of the twenty-one teachers who attended the professional development, three participants were used in this study. They all teach in the state of Iowa, therefore are facing the changes to be implemented in 2014 by the new Iowa Core curriculum, the new state education standards (IDOE, 2011). A brief overview of the participants is presented in Table 3-1.

Melissa is a 9^{th} grade general science teacher at an urban community high school (with approximately 2000 total students) in eastern Iowa. She has a Bachelor degree in Science Education. Prior to the start of the workshop, Melissa was interested in expanding her unit on work and energy to include issues of climate and climate change. She has been teaching for two years and expressed that she attended the PD looking for confirmation as to how to best teach her students science content. During the PD, she expressed concern with her ability to modify her unit, due to pressure from her colleagues to keep all science classes the same so it's "fair" for all students, regardless of which classroom they are placed in. However, she is excited to implement the inquiry approach from the professional development.

Table 3-1 Brief overview of participant information.

Name	Gender	Degree	District Type	Grade level	Content Area
Melissa	White Female	B.S. Science Education	Urban	9^{th} grade	General Science
Jonathan	White Male	B.S. Biology	Rural- urban proximity	7^{th}-8^{th} grade	Life and Earth Science
Robert	White Male	B.S. Biology	Rural	7^{th}-12^{th} grade	All Sciences

Jonathan is a 7^{th} grade life science and 8^{th} grade earth science teacher at a rural community middle school (with approximately 1000 total students) in central Iowa. Though the school is technically rural, it is approximately 40 miles from the Des Moines metropolitan area. Jonathan has a Bachelor degree in biology and came to the workshop hoping to gain more content knowledge about climate and weather. During the workshop, he was excited to incorporate the climate and weather content into his energy unit and apply the inquiry approach.

Robert is a 7-12 grade "all science" teacher at a rural private catholic school in northeast Iowa. He has an M.A.T in science education. Although not required by the state of Iowa to implement the new Core curriculum, Robert poses a challenge many teachers at small institutions face, which is a broad teaching spectrum. He recently restructured his 8^{th} grade science class to focus on earth science topics, ranging from astronomy, to geology, to atmospheric science. Additionally, he teaches a multi-grade level course on environmental science, where he focuses on human impacts on the environment. His goal from the professional development was to restructure his units to provide better content for the students and develop more student-centered activities. Robert showed interest in using the inquiry approach in his classroom.

Data Collection Methods

Since the proposed research design is a case-study approach, it was important that the forms of data collected for analysis have depth and come from a variety of sources (Merriam, 1998). Therefore, a combination of audio and video recordings for observations, field notes, teacher lesson documentation, interviews, and surveys were used.

Observations via Video Recordings

Data collection began when each teacher began their units, which was at the end of the fall semester for Robert's classroom and in the middle of the spring semester for Jonathan and Melissa's classrooms. Robert video recorded his teaching of each class during his climate unit, which he provided me. For Melissa and Jonathan's classrooms, I was present every day during their climate units to video record the teachers in their classrooms. Since the goal of this study is about how the teacher uses models as a part of their approach to teaching science concepts, it was not necessary to collect data from students. For this type of observation, analysis of the video informed research question two, which is aimed at describing *how teachers actually implemented science models into their classrooms*.

Documents

With permission from the participants, I collected all lesson plans, assignments, and other documentation the teachers used throughout their unit. Documents associated with the unit plan can be useful in helping to identify *how teachers use models*, as well as provide some insight as to their *perceptions about using models*. Some examples include lab worksheets, which the teacher provided to students with lab procedures, data collection tables, and follow up questions. There were also information sheets for the students with links to websites and online videos, and there were handouts that included homework and/or in-class worksheets with diagrams, graphs, or information and a series of questions for the students to respond to.

Questionnaire

At the end of the professional development, participants were asked to fill out a modified version of the Stages of Concern Questionnaire (SoCQ). This survey was developed to quickly assess the concerns teachers have about incorporating a new type of innovation into their classrooms. The researchers who developed the survey intended to make this a quick and easy evaluation, which was an improvement from the previous instruments with open-ended, short answer questions. The questions were developed, tested for reliability, and validated over a ten year span (Hall, George & Rutherford, 1979). Using the SoCQ provided information about what *the group of teachers perceive as challenges teachers face when implementing a new approach into the classroom*. Findings from the SoCQ were used to inform the questions asked during interviews of the three participants for this study. Information from this survey provided the researcher insight on common concerns the teachers were faced with prior to teaching their units.

Results from the SoCQ indicate that there is generally an even distribution of levels of concern across all categories, except in the involvement, collaboration, and consequences. Each category provides information about a particular concern a teacher might have about using an innovation, like science models, in the classroom. Involvement is the teacher’s concern about using the innovation in general. Awareness is the teacher’s concern about being able to find more information in order to understand the innovation. Personal/internal concerns are about the teacher’s ability to live up to the demands needed in order to use the innovation adequately. Management is the teacher’s concern with the tasks needed to use the innovation, such as reorganizing units, managing the classroom, scheduling concerns, and extra demands on their use of class time. Consequences are the concerns teachers have about how the innovation will impact the students, such as learning outcomes. Collaboration is about the teacher's concern with having to coordinate and cooperate with other people, such as other teachers or their administrators about the innovation. Finally, refocusing is a concern the teachers may face while trying to explore the universal benefits of the innovation, which generally involves applying the innovation across multiple units and years. A summary of the categories is provided in Table 3-2.

Table 3-2 Description of the different kinds of concerns teachers could have about the innovation presented during the professional development: the new science content and use of science models. [2]

Innovation: new science content and the use of science models in an inquiry-based classroom	
Involvement	Concern with using the innovation.
Awareness	Concern with having to search for more information about the innovation.
Personal/Internal	Concern with ability to adequately meet the demands needed to use the innovation.
Management	Concern with the tasks needed to use the innovation, such as reorganizing, managing, scheduling, and time demands.
Consequences	Concerns with the impact the innovation will have on students.
Collaboration	Concern with having to coordinate and cooperate with other people (i.e., teachers and administrators) about the innovation.
Refocusing	Concern with exploring more universal benefits of the innovation, such as applying it to other units or subjects.

Teachers involved with the professional development generally indicate little to no concern about their involvement in (or ability to use) modeling in general. This

[2] Modified from Hall et al. (1979).

indicates that most teachers are not concerned about being able to use models in their classrooms and may also indicate that they feel it is important to use them.

Results also indicate that many teachers indicated that they were very concerned about collaborating with others about the innovation. This indicates that teachers are not confidant that they can work with colleagues and/or administrators if needed to implement the innovation into the classroom. This outcome seems reasonable based on concerns expressed verbally throughout the professional development. Many teachers expressed that they were limited by rigid lesson plans, mandated by administrations either school-wide or district-wide. This is an indication of something that would need to be addressed in future professional developments, in order to better support the teachers.

Finally, several teachers indicated that they were very concerned about the consequences of the new innovation, whereas many others indicated mild and little to no concern. This indicates a divide in concern among the teachers as to whether or not the innovation will be beneficial to the students. These results could indicate that several teachers were unsure whether students would improve in learning about the concepts while using models, whereas others are fairly confident that the innovation could be helpful for student learning. In this respect, future professional developments should address student learning as a result of model use in inquiry classrooms. The results for this survey are provided in Figure 3-1.

Interviews

For Melissa and Jonathan, a series of semi-structured interviews were performed throughout the data collection period in order to gain insight into the teacher's thought processes (Merriam, 1998); one at the start of the unit, one after the unit, and at least one short reflective interview in the middle of the unit. Since Robert shared his videos after the unit was complete, two longer semi-structured interviews were conducted after analysis of the videos began. To establish rapport with the participants during the interview process (Creswell, 1998; Lincoln & Guba, 1985; Merriam, 1998), the researcher provided support for the teachers as the instructor of the PD. Melissa in particular felt unsure of how to properly include modeling into her unit and Jonathan was seeking information from climate scientists to include into his classroom activities. Although simultaneously playing the role of support and the role of researcher can create conflict (Wade, 1984), studies suggest that teachers do better with consistent follow-up with the PD leaders (Penuel et al., 2009), therefore it was necessary to overlap these roles in order to build rapport with the participants.

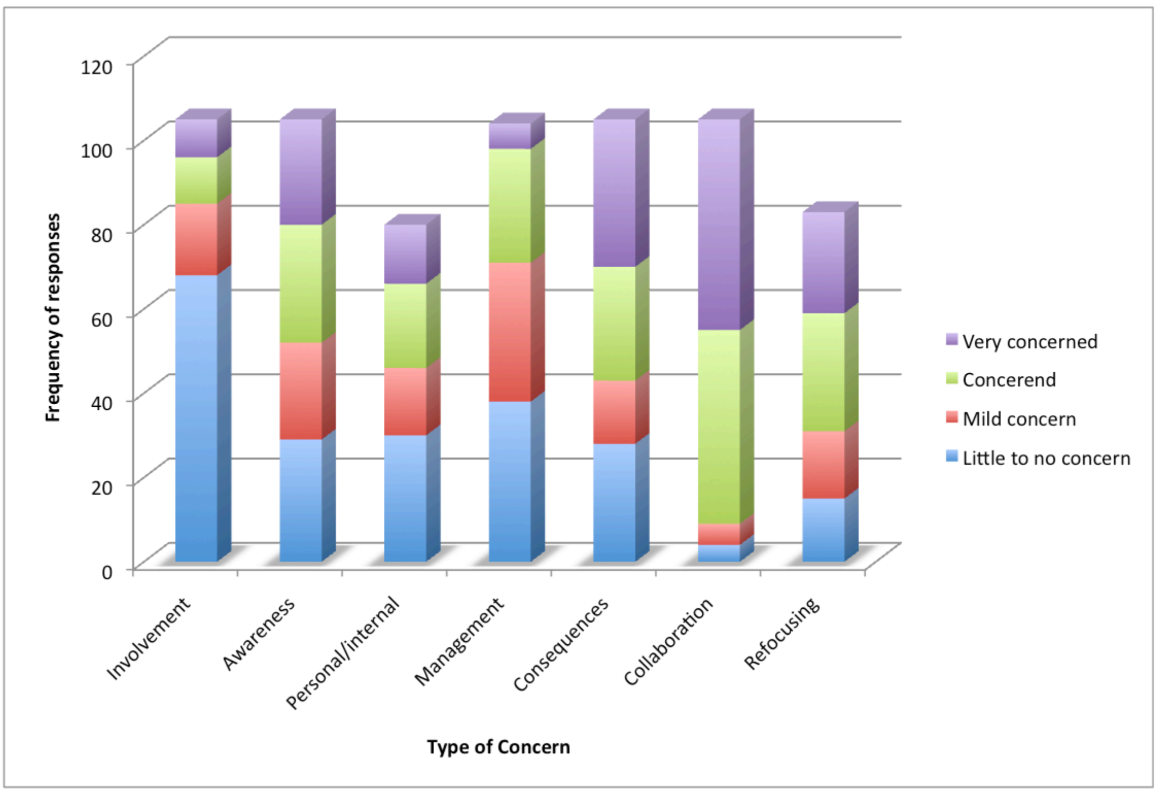

Figure 3-1 Results from the SoCQ given to all teachers at the end of the professional development. Results from this survey informed the interview questions that were asked to participating teachers in this study.

Taking on dual roles during the data collection process could also impact information the teachers provide during the interview process. It is reasonable to assume that since the teachers participated in the professional development, that they may not be completely honest during their interviews because they don't want to offend the instructor. To address this concern, I took care to be very explicit and clear with the teachers during the professional development that my intent is not to tell them the best way to use models in the classroom, rather I am curious to explore what approaches they use to include models into their own existing classroom strategies. Both course instructors modeled various approaches, while explicitly stating what the approach was; then followed up with time for the teachers to critique the approach and whether or not it would be something they could use in their own classroom. This approach established an atmosphere where the teachers could feel safe to express themselves freely to the instructors.

Since the goal of the interviews is to understand what the teachers think about using models, they should inform research questions one and three, which are their *perceptions of using models as well as challenges they faced while using models in their climate units.*

Interview protocol was developed for each of the interview stages. The first interview, referred to as the pre-unit interview, is designed to last approximately 30 minutes and the goal is to gain insight on the structure of the unit, how they plan to use models and inquiry throughout the unit, and any initial concerns the teacher has about the unit. The last interview is also designed to last approximately 30 minutes and the goal is to get their thoughts on what challenges they faced and to get their thoughts on how the use of models and inquiry transpired throughout the unit. Additionally, several short (approximately 10 minute) interviews and informal conversations occurred throughout the unit for Melissa and Jonathan. The goal of these conversations was to ask teachers to think out loud about model use, student learning, and inquiry approaches that they are using. All interviews were semi-structured with open-ended questions (Merriam, 1998). For the interview protocol, and a justification of the protocol and data sources for each research question, refer to Appendix B.

Data Analysis Methods

The analysis of the data was done with the major concepts outlined in Chapter Two of this dissertation, which include classroom dialogue, argument- and model-based inquiry, and the types of models used.

In a previous research study, five categories describing three stages of dialogue was developed based on K-5 grade classrooms during whole-class dialogue in a SWH classroom (Benus et al., 2013). These categories were compared with the five essential components of inquiry, as outlined by the NSES (NRC, 1996). A result of the comparison between the elements of dialogue and elements of inquiry lead to a comprehensive list of elements to consider in an inquiry-based classroom, which are: questions asked, evidence-based ideas, evaluating explanations, depth of idea exchange, classroom interactions, and conversation patterns.

There was also a discussion in Chapter Two about the comparison between argument-based inquiry and model-based inquiry to show that they are actually indistinguishable from each other. Based on that approach, one effective approach to utilizing models in the science classroom is to have students construct/revise them, use them to predict, use them to explain, and evaluate them.

In addition, there was extensive discussion about the variety of types of science models, therefore, while analyzing the data, it is important to consider the type of models the teachers use.

After consideration of the four concepts discussed above, an analytical framework was developed that allowed for full consideration of each of these elements in the participant's classrooms (Table 3-3).

Table 3-3 Framework used to analyze the data for this study.

	Constructing/ Revising Models	Using Models			Evaluating Models
		Predict	Have students Explain	Explain to students	
Type of Model Used	What types of models does the teacher have students construct/revise?	What types of models does the teacher have students use to make predictions?	What types of models does the teacher have students explain phenomena?	What types of models does the teacher use to explain phenomena?	What types of models do the teacher and/or students evaluate?
Questions Asked	How does the teacher engage students in scientifically oriented questions while constructing/revising models?	How does the teacher engage students in scientifically oriented questions while using models to make predictions?	How does the teacher engage students in scientifically oriented questions while students use models to explain phenomena?	How does the teacher engage students in scientifically oriented questions while using models to explain phenomena?	How does the teacher engage students in scientifically oriented questions while evaluating models?
Evidence-based Ideas	How does the teacher foster the use of evidence as the students and/or teacher construct/revise models as an explanation of a natural phenomenon?	How does the teacher foster the use of evidence as students' use models as a tool to make predictions?	How does the teacher foster the use of evidence as students' use models to explain phenomena?	How does the teacher foster the use of evidence as they use models to explain phenomena?	How does the teacher foster the use of evidence as the students and/or teacher evaluate models as an explanatory tool for a natural phenomenon?

Table 3-3 Continued.

Evaluating Explanations	How does the teacher support students while evaluating a model's ability to explain a natural phenomenon during construction/revision?	How does the teacher support students' ability to evaluate predictions of a model of a natural phenomenon?	How does the teacher support students while evaluating each other's explanations of a natural phenomenon while using models?	How does the teacher support students' ability to evaluate models while using them to explain a natural phenomenon?	How does the teacher support students while evaluating a model's explanation of a natural phenomenon?
Depth of Idea Exchange	How is the teacher engaging the students in the exchanging of ideas during the construction/revision of models?	How is the teacher engaging the students in exchanging of ideas while using models to make predictions?	How is the teacher engaging the students in exchanging of ideas while students use models to explain phenomena?	How is the teacher engaging the students in exchanging of ideas while using models to explain phenomena?	How is the teacher engaging the students in the exchanging of ideas during the evaluation of models?
Classroom Interactions	How does the teacher interact with the students while models are being constructed/revised?	How does the teacher interact with the students while using models to make predictions?	How does the teacher interact with the students while students use models to explain phenomena?	How does the teacher interact with the students while using models to explain phenomena?	How does the teacher interact with the students while models are being evaluated?
Conversation Patterns	What is classroom conversation like while models are being constructed/revised?	What is classroom conversation like during the use of models to make predictions?	What is classroom conversation like while students use models to explain phenomena?	What is classroom conversation like while teachers use models to explain phenomena?	What is classroom conversation like during evaluation of models?

All video recordings, documentation, and audio recordings were stored on an encrypted external hard drive, with file names providing a coded description of the teacher, source, and time of the data collection so that the information was easily identifiable. To keep track of the data, coded files with a more detailed description were recorded on an Excel spreadsheet.

The first two classroom observations and interview data collected were for Melissa's classroom. Both classroom audio and interview audio were fully transcribed. Transcriptions and lesson plans were analyzed using ATLAS.ti, where each phrase, line, or paragraph was assigned a code based on what question it answered in the analytical framework, with each data source providing specific information for each research question (Table 3-4). Often, lines of transcript would answer multiple questions, therefore received multiple codes. Once coding was complete, lines of transcript were extracted based on the categories of interest from the analytical framework; the goal was to identify patterns in the teacher's use of models.

Table 3-4 Summary of data sources used to analyze each research question.

Research question	Data source
What are teachers' perceptions of how the use of models support student learning in the science classroom?	Interviews Classroom observations
How do teachers use models to support student learning in the science classroom?	Interviews Classroom Observations Documents Field notes
What challenges do teachers have implementing models into their classroom?	Interviews Field notes

The procedure of transcribing and coding data in ATLAS.ti was not providing meaningful results because patterns were difficult to identify and the time spent transcribing and coding was too high. Therefore, the approach to data analysis procedure was altered. The first set of data reanalyzed was for Robert's classroom observations and the first analysis done was to identify segments in the video recordings where the teacher was using some kind of science model. Each segment was assigned a number as well as starting and ending time stamps as well as the type of model used. In an Excel spreadsheet, the whole segment was assigned a category code based on whether the students were constructing/revising models, using models, or evaluating models. All future classroom observations were analyzed this way.

After coding the segments for the first two videos of Melissa's classroom and all the videos of Robert's classroom, a more detailed coding procedure was used. Initially, every teacher utterance was given a code for the inquiry practice categories (conversation patterns, interactions, idea exchange, evaluating explanations, evidence-based ideas and questions asked; according to the design as summarized in Table #). However, after the first three videos, it became clear that each segment could be coded individually, since there were usually several examples of each inquiry category. Therefore, to save time coding the rest of the videos, only the most representative instances of the inquiry categories for each segment were identified, given the appropriate code, and then transcribed for reporting the results.

A similar strategy was used to analyze documents, field notes, and teacher interviews. The most representative instances of model use were coded for one of the five modeling categories in the analytical framework and the most representative instances of inquiry were coded for one of the seven inquiry categories. In addition, any teacher interview quotes that served as evidence to support an answer to one of the research questions, it was identified appropriately.

To analyze the data quantitatively, frequency charts were generated based on the number of instances of the five modeling categories. The class time spent on modeling and the use of models was also plotted. This technique is useful to visualize any patterns in the data (LeCompote, 2000).

To analyze the data qualitatively, trends in the categories were identified and summarized into detailed codes. These codes were then sorted into positive and negative cases, where positive cases were evidence to support the general trend seen for that teacher in that category and negative cases were evidence that does not fit within the general trend seen for that teacher in that category. After the codes were summarized, emerging trends were identified and themes were constructed.

Summary

This chapter justified the methodology used in the study. A qualitative approach was used in order to collect as much information from each participant as possible. The three participants teach either eight or ninth grade science that includes a weather and/or climate unit. Data was collected throughout their units, including classroom observations and teacher interviews. Teachers were chosen from a group of teachers who participated in a professional development about using inquiry to teach concepts in climate, weather, and energy; therefore the teachers were exposed to the approach to model-based inquiry described in Chapter Two. Data was analyzed by coding video segments where models were used in the classroom, using a specific analytical framework developed from relevant literature.

CHAPTER FOUR: RESULTS

This chapter will report the findings of the data analysis procedures discussed in Chapter Three for this study's three research questions, which are

1. What are the teachers' perceptions of how the use of models supports student learning in the science classroom?
2. How do teachers use models to support student learning in the science classroom
    a. In terms of the type of models used?
    b. In terms of inquiry approaches (questions, claims, evidence, evaluation, prediction)?
    c. In terms of elements of dialogue (idea exchange, interactions, conversation patterns)?
3. Challenges teachers have implementing models into their classroom?

A detailed analysis of each teacher will be discussed for each of the research questions, highlighting several themes that tie into the claims for each question. Overall, results indicate that teachers generally perceived models as physical representations useful for explaining a concept. Melissa and Robert use models as a way to explain a concept to their students, whereas Jonathan uses models as a way to have students explain concepts to each other. Additionally, all three teachers use models as a way to access students' prior knowledge. There is little evidence to suggest that teachers see or use models as representations, and no evidence to suggest teachers see models as a way to make useful predictions. Melissa mentions in an interview that she hopes her students understand that models are representations of the concept and not the literal concept. However she is not observed expressing this idea to her students explicitly. The teachers report very few challenges while using models in their classrooms; time constraints is one concern, but the other is that teachers feel unsure or unable to use models in a way that they believe best helps students learn. Generally, Jonathan uses models in a way that better aligns with the theoretical framework (discussed in Chapter Two) than Robert and Melissa and also reports fewer concerns and challenges. Jonathan also uses inquiry to a greater extent that Melissa and Robert, which could be an indicator that he has an easier time incorporating models into his classroom because he is already familiar with the inquiry approaches that align with their appropriate use.

Teachers' Perceptions of How the Use of Models Supports Student Learning in the Science Classroom

All teachers in this study perceive models as representations that can explain a physical phenomenon, such as drawings and three-dimensional objects. They said they use models in a way that they believe will help students understand the science concept better, which involved gathering students' prior knowledge, asking students to explain what they observe from the model, and asking students to build their own models. All teachers mentioned that students interacting with each other while using models can support student learning, both in small group and whole-class discussions. There is little evidence to suggest the teachers believe that models are a predictive tool and none of the teachers discuss model evaluation. There are three themes that emerged from the data, which will be discussed in detail in the sections to follow: a) Models can be used to explain a concept, b) Teachers perceive using models as physical representations, c) Models are a tool for student interaction.

Models Can Be Used to Explain a Concept

Teachers perceive that models can be used to explain a concept to students, or as a way for students to explain a concept to themselves or each other. All teachers described the importance of students using models to either explain their ideas or share their ideas with other students and with the teacher, particularly when students are trying to understand a science concept. However, as discussed in Chapter Two, one important aspect of science models is that they represent and explain a natural phenomenon.

Therefore, it is not only important that models are used both as a way to explain a concept, but it is also important to discuss the model as a representation of the concept. Appropriate use of models in the classroom should include an explicit link between the model itself and the concept it represents. However, none of the teachers discuss utilizing explanations to explore the relationship between science models and a science concept. This indicates that teachers might not fully understand the connection between a science concept and the model that represents it.

Robert describes models as a way to gather student's prior knowledge (Interview 3, 8.37) and engage students in the topic (Interview 3, 13.15). As he explained, "I want them to have ownership, have a say. They have something to contribute to the discussion instead of just sitting there being talked to" (Interview 3, 1.48). When asked why he chose to begin his class period having students sketch their understanding of the greenhouse effect and water cycle before giving them information on the topic, he said, "I need to figure out what they know. With such a diverse background of students, I had no idea where they were at" (Interview 3, 1.48). These responses suggest that Robert believes that it is important to gather their prior knowledge in order for him to tailor his lectures towards student needs and interests.

Although Robert does not explicitly discuss explanations as a part of the inquiry process, he does imply throughout interview 3 that it would exist within the process of engaging his students in the topic. He has his students sketch their ideas about how a specific science process works (such as the greenhouse effect, water cycle, and carbon cycle) in order to see what they know and what they don't know, and then uses this information to lecture to the class with embedded questions to elicit information from the group. In other words, Robert essentially uses models as a form of formative assessment. In addition, he believes his "interactive lectures" give students the opportunity to "take control of their own learning" (Interview 3). During these interactive lectures, Robert believes that he is giving the students an opportunity to share their ideas and explain concepts to their peers. In Robert's case, models are used primarily as a method of having students share their ideas with each other and are used to explain a concept to the students.

Similarly to Robert, Melissa also believes that models can be used to have students explain ideas to each other, which she does by providing a model-building activity that will "lead the students through" the concept (Interview 6, 8.50), and utilizing the models to explain what they think is happening (Interview 6, 9.05). In this case, the models themselves are the explanation for the science concept, and Melissa expects the students to learn the concept as it is represented in the model. She provides her students with instructions to build a model, and then asks them questions on their labs that require them to explain what they are seeing within the model. She also has the students work in groups and admittedly loves when there are disagreements among group members. She feels that these disagreements challenge the students to defend their own ideas as well as come to understand different perspectives. As she says:

> You do get some discussions where they're arguing back and forth. And I love it! … I think it's really healthy that they don't agree. I don't want them to agree on everything, I want them to help each other out and I want them to see other points of view. (Interview 3, 22.09)

In general, she believes that it is important for students to use models as a way to explain their ideas because it encourages them to explore personal ideas and "learn on their own" rather than simply taking her word for it (Interview 6, 30.16).

Like both Melissa and Robert, Jonathan believes that models are a very useful way to have students explain their ideas to each other, but unlike Melissa, models are used as a vehicle for students to generate explanations about a science concept. His classroom practices is based heavily off the 5E model, so all interview responses regarding model use is related back to the at least one of the 5Es. When asked to explain the ways models are used in his classroom, he made direct mention to specific phases of the 5E, such as, “When you think of the big scope of modeling… even in the exploration phase, like when they are exploring, they’re working with models just to figure out the components of it” (Interview 8, 6.45).

Unlike Melissa, Jonathan does not believe he spends much time explaining ideas to students directly; he says “I don’t want to lead them too much because I want to see what they come up with” (Interview 9, 1.25), indicating that he would rather let them work it out among themselves. In Jonathan’s case, models are used as a source of evidence to support students’ creating explanations about a science concept. Although Robert is observed using models to explain concepts to his students during lectures, he does not mention using them in this way.

Melissa is the only teacher who talks about using models as a way to share information with her students. She explains that she shares information in a way that she feels works best for her own learning “I have to go off of how I learned best… If someone tries to tell me something, I can’t remember it or learn it. But if I do it, then I can learn it or remember it” (Interview 6, 0.18). She further explains that her teaching style involves giving students information multiple times using a variety of methods “I think a kid can’t get it the first time around. They need to hear it again and again and again… I think the third time you give a child a concept, that’s when they start getting it” (Interview 6, 15.26). To present information using a variety of methods, she explains an idea to her students using several different models, such as demonstrations, drawings, and labs. She utilizes this approach because she believes it is important to explain concepts in a way that satisfies the variety of learning styles that exist within a classroom (Interview 5, 1.21). In this regard, Melissa is using models as pieces of evidence to convince students that her explanation is valid. Her ultimate goal is to use models to help students let go of their misconceptions, “If I just tell them that’s the way it is, it’s not going to stick with them and they’re going to keep those misconceptions.” (Interview 6, 1.05)

Teachers Perceive Models as Physical Representations

Teachers perceive themselves using specific kinds of models in their classrooms, which are most commonly physical representations such as drawings, graphs, scale models, or crafted material. Although none of the teachers discuss using the word "model" in their classrooms, they do all believe that they use models frequently in one form or another. The general consensus is that models can be defined as physical objects that represent a science concept. This notion is reflected in Jonathan's statement:

> [I've used] physical models like when we looked at data [in graphical form] from computer models. [The students] built… solar cookers…. Even in the final test some of them will be building certain models. Some of them might be drawing sketches of models, like how the water cycle works. Or find visuals and explain how the model works. So in those cases it's more of a physical model where they are using it to explain to me their level of knowledge. (Interview 9, 4.15)

Similarly, Melissa said:

> When I think of a model, I just think of it being a 3 dimensional [object]…. When we use models, we use a representation. Like a flash light and a Styrofoam ball…. We try to let them figure why [they have] all the parts we just gave them. What are [they] for? (Interview 6, 30.53)

Jonathan mentioned that his students use their own mental models to construct the physical models in class, but other than that, non-physical models (such as conceptual and mental) were not discussed. Even though both Melissa and Robert discuss the importance of gathering students' prior knowledge, they do not discuss the connection between the physical models used in the classroom with the mental models students already have. They appear to perceive students prior knowledge as a database of information rather than as a complex conceptual framework, which may indicate that they have a different perspective on student learning than that used in the framework discussed in Chapter Two of this study. In this case, Jonathan is very different from the two other teachers in this study because he is able to articulate a connection between model building and conceptual understanding, which will be discussed in this section.

When asked to define science models, all the teachers struggle to construct a concise definition, and generally resorted to listing examples. For example, when asked what kinds of models she uses in her classroom, Melissa pauses for a few seconds before responding with "I guess I'm very uneducated [about what qualifies] as a model" (Interview 6, 12.58). Then, Melissa struggles to give a definition because she believes that just about anything can be a model, however she cannot describe the qualities that define a model beyond being a physical representation of a concept that she wants students to ultimately learn (Interview 6, 3.06); she admits to using models this way frequently in lab settings (Interview 6, 14.56). When asked to give an example, she points to a pile of supplies on the table in front of her, which include a Styrofoam ball, a flashlight, ruler and some pencils, which were used that day in a lab about Earth's seasons (Interview 6, 14.56). However, she also acknowledges that things such as graphs and photographs can also be models *when she uses them to have students explain ideas* (Interview 6, 30.53).

Most often, she says that model use is unplanned in her classroom (Interview 5, 1.59) and generally occurs when Melissa is trying to explain an idea to her students and wants to be sure she covers many different examples to support the idea. Her ultimate goal is to use physical representations as evidence to move her students' understanding of a concept towards her own understanding of the scientifically-accepted explanation for the concept.

Similar to Melissa, Robert discusses that models are generally physical representations, but he has very specific examples of what he uses in his classroom, which involves drawings and graphs. Robert said, "I like drawing, I have an art minor. But a lot of times… [the students] can never remember the word [for a concept]… but they can draw [the process] instead" (int0301, 9.25). Therefore, it is no surprise that Robert is frequently observed asking his students to draw concepts like the greenhouse effect and the water cycle. After students do lab activities, he also asks them to display their results using graphs as a visual representation of data (Interview 1, 1.33). In his classroom, the drawings and graphs typically provide the teacher with a better idea of the students' current understanding of the concept (Interview 3, 23.36), which he utilizes both in class as well as on exams (Interview 3, 21.25). He explains that he prefers the students understand the processes and is less concerned with their ability to recall specific terminology (Interview 1, 7.00). He recognizes that students may have trouble remembering specific details, but can generally visualize or describe a process, which he accesses by utilizing visual models. He believes that encouraging students to sketch and share their ideas with other students is a way for them to remind each other terminology or definitions that they may have forgotten.

Unlike the other teachers, Jonathan eventually comes to define models as "any tool that can help further understanding about a concept" (Interview 7, 6.59). In an interview, he describes the models that students build as "a tool that has information about [the topic] and is organized in a way that works for [the learner]" (Interview 7, 6.36). As a result, Jonathan describes the type of models he uses as theory-based models; meaning students design, construct, test, and describe their own physical models based on their understanding of the concept (Interview 7, 6.50). Additionally, he says that he does not like to show models to his students as a way to explain concepts to them. He would rather have students construct meaning from them for themselves (Interview 7, 5.10). Jonathan explains:

> I don't do a lot of modeling as demonstration because I think that funnels them too much into one way of thinking. I would rather pose questions to them and see what they come up with because they will come up with things I would have never even envisioned. (Interview 7, 5.15)

Jonathan perceives that the physical models he has his students build in class are representations of their conceptual understanding of a process. He has them build, test, and evaluate their models with the goal being that as students continue to refine on and improve upon them, their understanding of the concepts conveyed within the model will also be refined. Jonathan's discussion about the connection between the physical model and the students' mental model indicates a perspective on learning that better aligns with that used to develop the framework discussed in Chapter Two.

Models Are a Tool for Student Interaction

Teachers think that models can be used to support student learning by having them interacting with each other around the models. Field observations of the classrooms indicate that the majority of all student talk occurred when students were constructing or revising models within small groups; this occurred because, in interviews, all teachers believed that students could learn from each other in those kinds of learning situations. Each teacher had a slightly different perspective on how student learning can occur through small group work, which seemed to be based on their individual teaching philosophies as evident from each teachers' interviews, which will be discussed in more detail throughout this section. Differences between the teachers, however, exists in how the teachers perceive learning to occur during student talk, which will also be discussed in this section; Robert believes that information is shared/exchanged between students during small group work, whereas Melissa and Jonathan believe that students can challenge each other's ideas and construct a better understanding of a concept through argument.

Robert asks his students to draw visual representations of science concepts in small groups of two to three students. Robert explained that he uses this approach because he feels it helps students remember concepts from prior coursework that they may have forgot (Interview 3, 14.20). As he explains:

> [The students] collaborate more than anything else [while working in small groups]. I wouldn't say it's learning, but it's more like they get to share ideas to make a cohesive thought… (Interview 3, 14.30)

Therefore, Robert does not consider this process learning, since students are working to recall prior information and not obtaining new information. It seems as though Robert believes that learning occurs during his whole class lectures because they are getting new information from both the teacher as well as each other (Interview 3, 14.40). As he says:

> My goal [during whole class discussions] is for the students to learn from each other. Like math problems you can do two different ways… Both give you an answer, but its two different ways. So in [whole class] settings, where we are working on problems or big ideas, they can learn from each other. (Interview 3, 14.30)

Therefore, Robert believes that when students are constructing models from prior knowledge, learning is not taking place. However, they do learn once the students receive new information, which can come from either the teacher or other students. For Robert, the models are tools to help students share ideas with each other, however he does not seem to believe that most students learn through the process of constructing models, which was suggested when he was asked in an interview if he believed learning occurred during the model building process. He responded: "I know it made connections for some students…Given more time, I don't know if that would have teased out into more interest and better discussion [or not]" (Interview 1, 3.01). In general, he avoided using the word "learning" with regard to model construction and stuck with terminology like "share ideas" and "remember".

Alternatively, Melissa and Jonathan believe that students working in small groups to construct models can lead to learning because students can share ideas as well as challenge each other's ideas. For example, Melissa had students construct models in small groups using a prescribed laboratory procedure. She occasionally sets up groups based on students' prior ideas because she explains that she loves it when they argue different ideas with each other (Interview 6, 20.51). She believes this process is important because it teaches her students to support their ideas with evidence (Interview 6, 23.04), which can ultimately lead to "innovation" (Interview 6, 22.20). Ultimately, Melissa feels that her main job is to improve students' critical thinking skills (Interview 6, 26.47) and to be "better citizens" (Interview 6, 25.41), which can be supported when students working in small groups argue their ideas (Interview 6, 22.09). As she explains:

> You do get some discussions where they're arguing back and forth. And I love it! … I think it's really healthy that they don't agree. I don't want them to agree on everything, I want them to help each other out and I want them to see other points of view. (Interview 6, 22.09)

Similarly, Jonathan expects that learning can occur within small group use of and construction of models as a result of conversation that takes place. Although his responses to interview questions indicate that he has not spent much time thinking about the conversations his students have during the inquiry process, he does talk about how the development of their models is a significant indicator of the quality of group conversation that took place, saying:

> For the most part, if I look at their final product… I get to see some really good science going on and I could see that there were some good conversation pieces going on. (Interview 9, 11.45)

Jonathan's approach differs from Melissa's in that he generally allows students to resolve disagreements by breaking the group apart and running separate experiments with separate models; but at the end of the activity, he expects them to compare the results gathered from each model. Melissa prefers to have the students argue with each other, which she believes builds critical thinking skills in her students. Jonathan Seems most interested in having the students test their ideas to see what works best, rather than argue with each other. Conversely, Robert does not talk about critical thinking skills or model development as an important aspect of learning. Rather, he perceives the transfer of new information to be the most important aspect of learning.

How Teachers Use of Models Supports Student Learning

In general, models were visual or physical representations used as evidence for teachers to explain a concept to students. There is little evidence that teachers evaluated models or used them to make predictions. Even though they were primarily used as evidence, model use in each teacher's classrooms took up a large amount of class time for each case (Figure 4-1). Teachers in this study were generally observed using models in the form of physical representations, which included three-dimensional objects, drawings, graphs, photographs, and videos. Each teacher had their own approaches to inquiry, but they all used models as pieces of evidence to support student learning about a science concept. They also tended to use models as a way to drive student discussion, usually asking students to talk about the model.

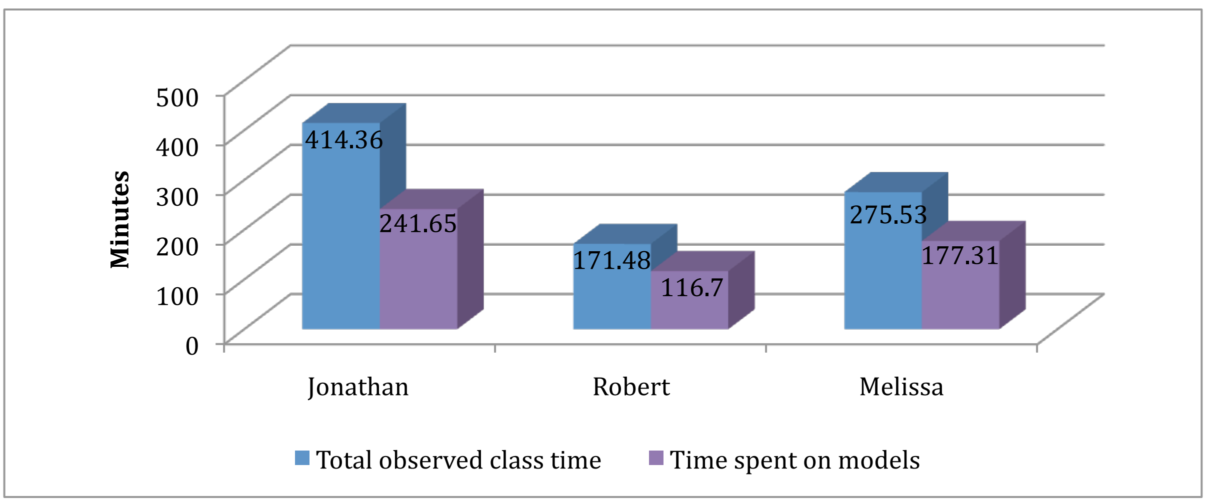

Figure 4-1 Total amount of class time observed for the unit (blue) and the total amount of class time spent on models (purple) for each teacher in the study.

As discussed in the previous section, each teacher had different perspectives as to how they used models in their classrooms as well as the inquiry approaches they use to teach science content. In this section, observed inquiry and model-use practices will be described for each teacher and the relationship between each teacher's practice and the theoretical approach will be discussed. Summaries will be presented for each teacher's inquiry approaches based on the theoretical framework discussed in Chapter Two.

Models Were Physical Representations of a Concept

Teachers used various types of models in their classrooms, which can be described as physical representations (either 2-dimensional or 3-dimensional) that visually and/or physically represent a science concept. Each teacher generally used a variety of models, which included pre-constructed, teacher-constructed, and student-constructed varieties. Robert and Melissa had students build physical models within a traditional lab setting, with an outlined procedure and an expected outcome. Jonathan asked his students to design a test on their own and construct a physical model that would be used to do the testing on. In all cases, the results of the model building was to use the models as evidence to support student understanding of a science concept.

Robert: Drawings and Graphs

Robert's classroom used a couple different kinds of physical models. One type of model was a structured lab that involved students using test tubes filled with various gases (normal air, carbon dioxide, and water vapor), which represented different kinds of greenhouse gasses within the Earth's Atmosphere. In this case, they were physical representations of the Earth's atmosphere (Interview 3, 6.32) Using this model, students essentially isolated two different greenhouse gasses and demonstrated the warming capacity of each of them as compared with normal air (the control test). During this lab, students took temperature readings (Observation 4, 1.41) and then made graphs of the data; the graphs were posted at the front of the classroom and the teacher lead the class in a "discussion" (Interview 2) about the results (Observation 5, 9.28).

In addition to the lab, Robert asked students to draw representations of the greenhouse effect, carbon cycle, and water cycle (Observation 1, 9.12; Observation 2).

These drawings were based on prior knowledge as well as any readings Robert assigned before class (Interview 2). Therefore, Robert was asking students to create physical representations of their conceptual understanding of a concept (e.g., mental models).

Robert spent a total of 116 minutes of class time using models and 35 minutes of that time having the students construct models; therefore, the student drawings took up the most classroom time of all the modeling activities he did. However, he also occasionally generated models on the white board during the whole-class discussions (Observation 3, 23.25), which included sketches like a diagram of a plant growing out of the ground to emphasize the exchange of oxygen and carbon dioxide during photosynthesis (Observation 3, 23.25), math equations such as the formula to calculate energy required for water the change phases (Observation 3, 23.23), and graphs such as a sketch of the atmospheric carbon dioxide increase over the last 100 years (Observation 3, 18.23). Robert used these models to support him as he explains various concepts to the students (Observation 3, 36.13).

Melissa: Lab Work and Demonstrations

The most common type of models that Melissa uses in her classroom are physical objects within a lab-based setting. For example, she had the students explore surface heating with cups filled with different substances, such as water, sand, and dirt. She would set up the lab for the students prior to the class period and provide them with a specific lab procedure that she expected them to follow (Document 1). She tells her students explicitly, “I said to keep the thermometers above the cup. Follow the procedure!” (Observation 6, 28.27). The students were asked to collect data from the models and use their evidence to explain in their own words what they think is happening.

Melissa also uses a lot of demonstrations and other physical representations in her class. When her students are not collecting data in the lab, Melissa is usually at the front of the classroom utilizing a model to provide information to the class or to elicit ideas from the students. These included physical actions (such as moving students around the classroom to represent molecule movement) (Observation 7, 9.43), pictures (Observation 7, 11.30), videos (Observation 7, 36.59), flow charts (Observation 6, 15.14), photographs (M0305, 13.55), graphs (Observation 10, 18.25), smart phone application (Observation 10, 40.12), and concept maps (Observation 6, 3.45).

One thing Melissa does that none of the other teachers do is occasionally remind her students that the models they are using to represent certain concepts (such as the earth and the sun) are not exactly like the way the earth and the sun work in real life (Observation 11, 14.48) ("Now is there really a stick pointing out the top and bottom [of the Earth]?"). This indicates that Melissa is both aware that models are representations and concerned about the misconceptions that could arise for the students as they use the representations to understand a physical phenomenon.

Jonathan: Student-Designed Physical Constructions

Jonathan has students design and develop their own physical model by using their prior knowledge to predict the best design (Document 4). For the unit, students were challenged to design and construct the most effective solar cooker possible using only recycled materials. After doing some online research and group discussions students constructed and tested the models, then collected and represented the data in graphs and tables (Document 6). Students had the opportunity to test their solar cookers several times throughout the unit, collecting data and then revising their models based on evidence they gather from quantitative (Observation 20, 5.21) and qualitative (Observation 20, 6.25) observations. Finally, they shared their models as well as what changes they made in their model with the rest of the class (Observation 21, 37.49). Jonathan asked his students to specifically indicate which aspect of the model they changed the most: the material used to absorb heat or the reflective material. While doing this model construction and revision activity, the students were constructing physical representations of their conceptual models (i.e., their initial understanding of how solar cookers work), tested it and improved upon it based on evidence, and represented their findings using graphs and tables.

Occasionally, Jonathan talked to the whole class in a sort of lecture format. Jonathan referred to a math equation on multiple occasions, namely the equation indicating that solar energy is equal to the reflection, transmission, and absorption of the material, (Observation 20, 6.38) and would show graphs like those that indicate global temperature change over the past 100 years (Observation 17, 11.15) and YouTube videos that are a potential source of information for the students, such as those that describe a working design for a large-scale solar cooker (Observation 16, 23.58). When Jonathan used models during whole class discussion, he presented the students with relevant information, which appeared to be information that he hoped would either help his students design a better solar cooker, or to remind students about the big idea of the unit. It would seem that when Jonathan speaks to the class as a whole, he is attempting to draw ideas the students develop about their solar cookers back towards the big idea.

Models Were Used as Evidence to Support a Concept

Teachers used models as pieces of evidence to support the teacher's conception of a concept and used them to explain the concept to their students using several approaches to inquiry. In all cases, the teachers utilize explanations when discussing science concepts and models are used as pieces of evidence to support an idea. Although models were used to explain science concepts, students formulating explanations about the models themselves was rarely observed, which can be a limitation when it comes to student's developing an understanding that science models are science concepts. This trend was observed qualitatively as well as quantitatively by observing a breakdown of how models were used in each teacher's classroom (figure 4-2). Of the class time spent working on models, the majority of the time was spent explaining the concepts associated with each model; very little time was spent evaluating the model itself or using models to make predictions. Except for Jonathan, each teacher generally used models as a way to explain concepts to students rather than as a way to help students explain ideas to each other (Figure 4-3).

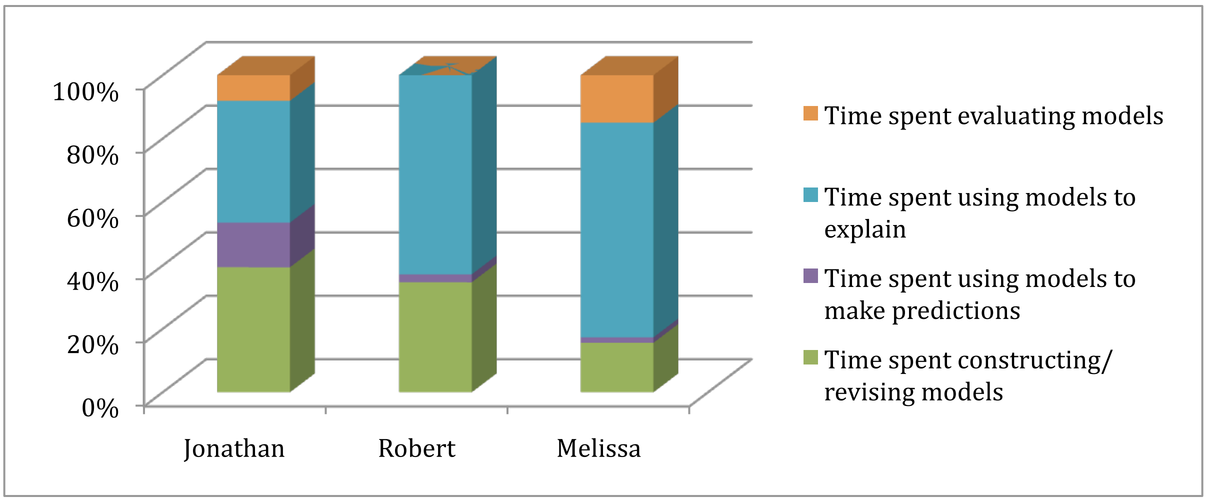

Figure 4-2 Of the class time spent using models, the breakdown of time spent evaluating them (orange), using them to explain (blue), making predictions from them (purple), and constructing/revising them (green) for each teacher's classroom.

<u>Robert: Utilizing Students' Prior Knowledge</u>

There is very little evidence from the video data alone to indicate that elements of inquiry are being utilized in Robert's classroom. However, Robert does indicate in an interview that he uses only a couple of elements of inquiry, which involves an interactive lecture (Interview 2) and utilizing students' prior knowledge (Interview 3, 8.37) to drive the content provided in those lectures (Interview 3, 17.15). As Robert explains, "I use elements of inquiry" (Interview 3, 4.10) "A discussion allows me to ask questions, access prior knowledge and have the students justify or explain their answer" (Interview 2).

With this information in mind, the video analysis does provide some evidence to support those elements of inquiry.

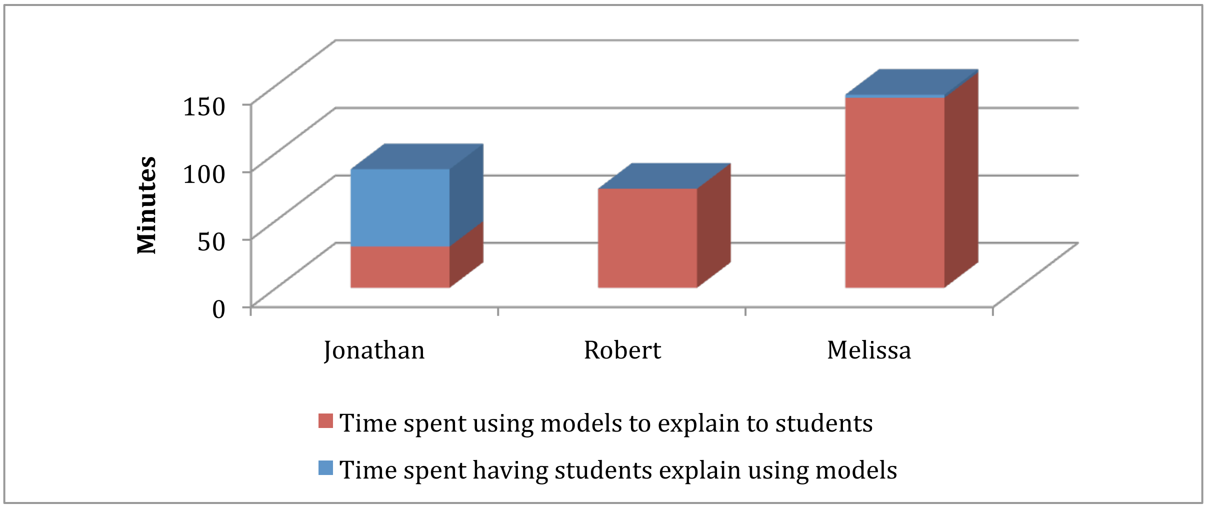

Figure 4-3 Time spent having the students explain models (red) as compared to the teacher explaining models to the students (red) for each classroom.

The teacher begins each class period by asking students to draw a picture of a science concept, such as the greenhouse effect (Observation 1, 9.12). Students work in pairs to construct their current understanding of the greenhouse effect, and will generate drawings similar to the one represented in Figure 4-4 (Observation 1, 9.34). The teacher wanders around the classroom (Observation 1) either responding to student questions or asking students questions about their drawing. Students frequently ask clarification questions about the activity or seek affirmation about their drawings (Observation 1). Robert asks the students questions about their drawings, such as information seeking questions like, “what does that mean?” (Observation 1, 21.38). Robert is also observed reminding students of information they are missing from their model or asking them to clarify certain aspects of their models. This indicates that Robert is looking for specific content in the models and expects students to be able to explain the concepts through drawings.

Figure 4-4 Student drawing of the greenhouse effect in Robert's classroom. Used as a way to gather students' prior knowledge.

After model construction, Robert asks students to post them at the front of the room before he provides information to the whole class. During these whole class lectures, the teacher is observed asking students information-gathering questions, such as "water falls as….?" (Observation 2, 12.4) and "what causes it to evaporate?" (Observation 2, 25.43). Students respond one at a time and Robert provides feedback to each response, by confirming the answer, saying things like "exactly" (Observation 2, 16.31) and providing follow up information "Precipitation. That's water that [falls to] the ground" (Observation 2, 26.18) or by calling on another student to respond. When a student provides an answer the teacher is not satisfied with, he will generally not say anything and wait for another student to provide a new suggestion (Observation 2, 26.13). This behavior indicates that Robert is usually surveying the class for a particular answer (Observation 3, 33.33). Although the student drawings are posted on the board at the front of the room, he does not refer to them in any clear way. In this instance, Robert uses questions as a way for students to interact with each other as he provides them with information; however Robert's goal is to ultimately transfer information to the students because he will clearly accept or reject student responses and write information on the board for students to copy.

Robert utilizes explanations by having students explain what they currently know about a concept through their drawings, and then explains concepts to students in his lectures in a way that "fills in" aspects that he believes were missing or weak in the student's initial drawings. Robert's ultimate goal is for every student to understand (and potentially reproduce) a drawing that is consistent with the teacher's conceptual understanding of the concept.

When compared to the theoretical framework for this study, Robert's use of models in inquiry aligns with the "Brainstorm" and "generate draft model" stages when he asks students to draw concepts. The teacher begins his class period with this activity, which appears to be an activity for students to generate a model based on prior knowledge. Generating a draft model also provides students with the opportunity to brainstorm terminology and concepts about the topic they were modeling. After the students generate their models, Robert has the students display their models, however there is no discussion about those models evident, therefore models are not being critiqued or negotiated.

The other type of model Robert uses in his classroom is within a lab setting, where flasks with various greenhouse gases are set up for data collection. In this example, Robert has the students collect temperature data from each flask when a heat lamp is turned on them. He then asks students to graph their data on a white board, which are displayed at the front of the classroom during one of Robert's whole-class discussions. In this instance, Robert is utilizing physical representations of the atmosphere and graphs of the data collected to convince students that certain greenhouse gases lead to a larger temperature increase than others. During the whole class discussion, Robert explicitly points out which greenhouse gases were stronger, which indicates that he utilizes the graphs and the lab-based models as evidence to convince his students that they should understand the concept in a way that aligns with his understanding.

Utilizing models in a lab-based setting align with the theoretical framework steps "derive evidence", in that the teacher sets up the lab for the students and provides them with a step-by-step procedure to collect data. Robert set the lab up before the students arrived in class, filling three flasks with three different gasses: air, carbon dioxide, and water vapor. Then, he gave explicit instructions to the students as to how they will collect the data. The set up for the lab is depicted in Figure 4-5. After data collection, Robert asked his students to graph the data. During the lab procedure, Robert does not ask the students to design their own test, to make predictions about the outcome of the test, or modify their initial models based on the evidence they collected. Rather, he asked them to collect the data and analyze the results. Although the student-generated graphs are displayed to the class, they are not critiqued or negotiated. A summary of Robert's observed inquiry practices and his perceptions of his inquiry practices is portrayed in Figure 4-6, which is framed after the theoretical case presented in Chapter Two.

Figure 4-5 Set up for Robert's greenhouse gas lab.

<u>Melissa: Student Explanations</u>

Melissa mainly uses models as evidence to help students understand an idea. She begins most class periods with a question written on the board and is usually followed up with Melissa using models to demonstrate a solution to the question. For example, Melissa spent one class period on the cause of the seasons. She began the class period by drawing a picture (Figure 4-7) on the board (Observation 11, 4.47) and asking the students to explain what they think is happening in the picture: "Is the Earth on a fixed tilt? Or is it a tilt that goes back and forth? From your lab that you did, have you discovered that yet?" (Observation 11, 4.51). After allowing a few students to respond, Melissa provides them with information about what the picture represents (Observation 11, 5.33). Then, the teacher breaks the class into small groups and sends them into the lab, where she has provided them with materials and a handout with lab procedures and a few corresponding questions. She expects the students to follow the procedures because she constantly reminds them to do so (Observation 6, 8.27), which indicates that the procedures are aimed at providing the students with specific evidence to convince students to think about the concept the way the teacher does. Melissa appears to be presenting students with the big idea of the day's lesson, first by hearing their ideas, then telling them, and then by showing them during the lab procedure.

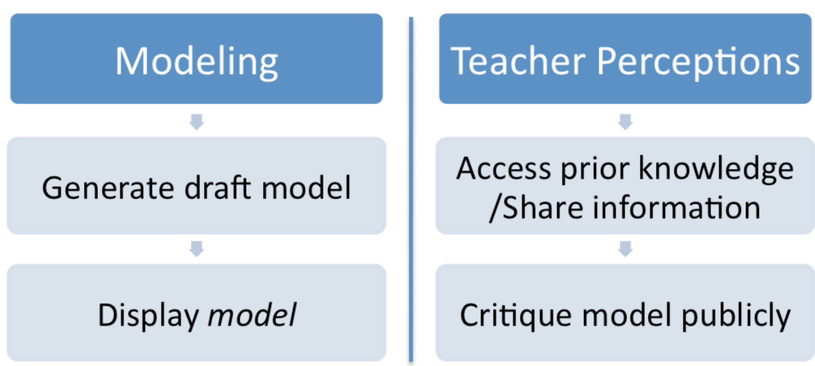

Figure 4-6 Summary of Robert's observed use of model-based inquiry and his perception of model use.

During Melissa's lab, she spends the majority of her time visiting each group to answer questions or check on progress. Some comments she makes during her small group visits include, "You decide based on what you see" (Observation 11, 17.19) and

"In my orbit around the sun, when I get to here, where is the axis pointing? It's pointing away from the sun" (Observation 11, 15.24). However, she will also clarify lab procedures for the students by showing them what she expects them to do (Observation 11, 15.09). During these small group labs, the teacher is providing the students with exactly what she wants them to do, which indicates that she is trying to convince the students to understand the concept in the way she understands it. By asking students to explain their ideas explicitly, she is attempting to get a better picture of what the students currently understand about the concept in order to move them towards her conception.

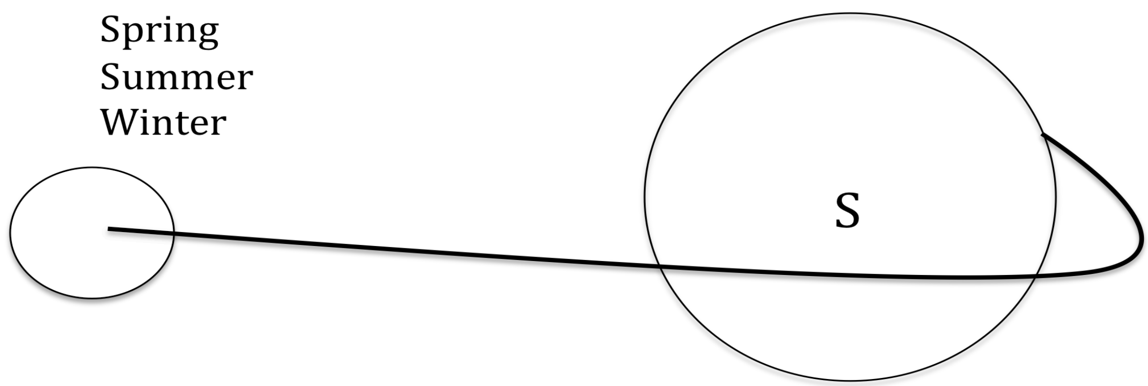

Figure 4-7 Recreation of the figure Melissa drew on the board for her class to discuss regarding the cause of Earth's seasons.

At the end of the class period, Melissa speaks to the whole class again, reiterating the idea that Earth's seasons are caused by the tilt of the Earth rather than the Earth's proximity to the sun, which is the big idea she wants the students to understand from the day's lesson (Observation 11, A3.07). Melissa's actions in her classroom indicate that she is interested in helping her students understand one big idea; which she tells them, shows them using models as evidence, and then tells them again. Throughout this process, however, she does ask students for constant feedback, using information-seeking questioning and by asking for students to explain their ideas, which will be discussed further in the next section.

Melissa's approach to using models within inquiry utilizes the "make prediction", "gather data" and "derive evidence" stages. Melissa asks students to brainstorm ideas during group work before they begin their labs. Models are frequently used during this stage, however they are usually something the teacher presents the students, such as a drawing on the board or a demonstration, rather than a student-generated draft model. The teacher set up the lab materials for the students and provides them with a procedure to follow. Therefore, the students did not generate a test themselves, but they did use lab-based models to gather data and derive evidence. Rather than utilizing that evidence to create models of their own, students use the evidence to generate explanations (i.e., make a claim) about the science concept. The explanations occur as a result of the evidence collected from models, but students do not create or modify models based on the evidence provided. A summary of Melissa's observed inquiry practices and her perceptions of her inquiry practices is portrayed in Figure 4-8, which is framed after the theoretical case presented in Chapter Two.

Jonathan: Construct, Gather Evidence, Evaluate, Modify

Jonathan uses student-constructed models just about every day in his classroom. When students are gathering information, he uses worksheets and videos as a part of their information gathering process; and that information is always centered on the development or revision of a student model.

Jonathan's unit consists of a large, multi-step project where the students work in groups to design, build, test, modify and evaluate a solar cooker. The teacher begins the project by providing students with information about solar cookers (Observation 12, 4.15) and does so by explicitly mentioning the big idea for the unit: "The big idea is what? Why are we doing this? ... By turning on our stove or burning charcoal, what are we doing? … We are trying to eliminate greenhouse gases [by using solar cookers]" (Observation 12, 5.50). Then, the students worked in small groups on a design for their solar cookers, utilizing a worksheet that guides them step-by-step through decisions they should be making before building the model, such as what materials are most reflective, what material absorbs most heat, and where absorbent/reflective materials should be placed relative to the sun and to each other (Document 4). After students draw a draft design of their model, the teacher approves it and the students begin to build.

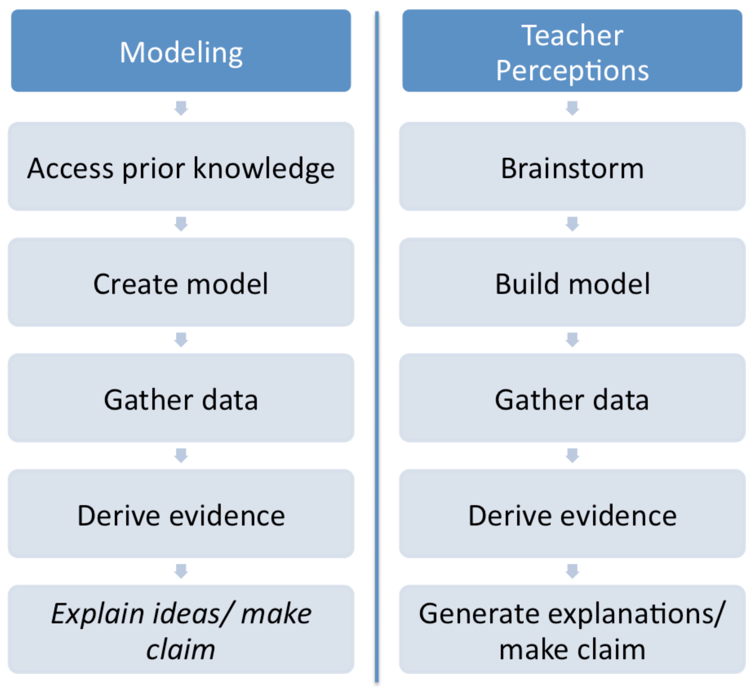

Figure 4-8 Summary of Melissa's observed use of model-based inquiry and her perception of inquiry/model use.

Once the students build their physical model, Jonathan asks them to test their solar cookers by using thermometers to collect temperature data (Observation 14, 20.20), and then make necessary modifications (Observation 15, 10.38). As the students build, test, and modify their models, the teacher periodically provides them with relative information, using either a brief lecture format, such as when he presented his students with the equation for solar energy (Observation 14, 15.55), by showing a You Tube video that provides students with potentially useful information, such as the video describing how a working solar cooker was constructed (Observation 12, 37.51), or by providing the students with information sheets providing them with informative websites about methods to harness the suns energy (Document 6). This behavior indicates that Jonathan is trying to provide students with information that will guide them towards a better solar cooker design, and having them collect data from their models can provide students with evidence needed to convince them that their ideas about how solar cookers work might need to change. However, he did not require that the students utilize the information he is providing; rather, he encourages them to reference these sources as they are modifying their models. Jonathan appears to be serving as a resource for the students, either by utilizing direct information transfer, such as when he says, “From the picture, you could say that the globe is naturally changing…. But there are other explanations we have to look at as well” (Observation 17, 18.31). Jonathan will also provide them with outside sources to help the students gather information on their own (Document 6); ultimately it is up to the students as to whether or not they will utilize any of this information.

After a few weeks of data collection and modification of student solar cookers, Jonathan had each group share what they learned about harnessing the energy of the sun with the rest of the class (Observation 21, 21.38). He provided a grading rubric to the students, which outlined findings that they were expected to report to the class. He asked them to provide a detailed description of how their solar cooker design worked most effectively to harness solar energy, discuss pros and cons of solar energy, use at least one visual, and cite appropriate resources. The visual representations the teacher suggested his students use included various types of models, such as graphs, pictures, drawings, and tables (Observation 15). While students presented, the rest of the class was generally very quiet, only asking a few clarification questions to the presenting group if they asked anything at all. The teacher asked each presenting group various clarifying questions, such as “That was one of your redesign features, right?” (Observation 21, 24.01), and even presented new evidence on occasion like, “Maybe if we had a thicker plastic material, it wouldn’t have been as affected by the wind” (Observation 21, 27.31). In one instance, the teacher asked the class if they had any questions for the group, one student asked a question about which variable the group tested and the teacher provided a response on their behalf, saying “Sounds like they focused on the reflectors” (Observation 21, 34.20). The dialogical interactions that occurred throughout this unit will be discussed in detail in the next section.

After each group presented their findings, the teacher spent some time talking to the whole class in order to emphasize the idea that the variables changed in the solar cookers to make them warmer also applies to the atmosphere to cause global warming. He also told the students that he is looking for their ability to apply what they learned about their solar cookers to the issue of climate change. This indicates that Jonathan had clear learning goals for the students and wanted to be sure they got it. He told his students:

> All words from the word [bank] must be addressed [in your final project]… These aren’t all the words we saw this unit, I picked out the big idea words. The ones that I want to see that I think you should know and I want to see what level you know them at. (Observation 22, 4.31)

Jonathan’s use of models in inquiry utilizes the 5E approach and also aligns fairly well with the theoretical framework presented in Chapter Two. His students gather information about the project before they “generate a draft model”. The students decide what variable they will test, which indicates that they are making a prediction because they have to choose one aspect of the model that they believe could maximize the results. After choosing their variable, the students determine how they will test it, “gather data”, “derive evidence”, “modify the model”, and then retest and modify the model again. Most groups of students did this three times; others did so more often. While preparing to share their models with the rest of the class, they generated a claim that was not clearly linked to the testing or modifications made to their models. Each group then shared their models and claims with the class, but critique and negotiation of the models or claims was not evident; which will be discussed further in the next section. A summary of Jonathan’s observed inquiry practices and his perceptions of his inquiry practices is portrayed in Figure 4-9, which is framed after the theoretical case presented in Chapter Two.

Models Were the Focal Point of Conversation

Models were used as dialogical focus points during class discussion and the teacher interacted with students in ways that moved discussion towards the teachers’ conception of the phenomenon. Each teacher in the study used a combination of both small group and whole-class discussion, generally presenting models for students to talk about. All teachers asked students to do some model construction; however Robert and Melissa did so in a structured environment with pre-determined expectations of what the models should look like, whereas Jonathan seemed to have less structure and placed more emphasis on the students being able to come up with their own model designs based on what each group wanted to experiment with. Regardless of how models were used to drive discussion, when the teacher took part in the conversation, they each had their own methods to help move student conversation towards a better understanding of science concept.

Robert: Small Group to Lecture

In Robert’s classroom, the class period begins with students working in pairs to draw a representation of the greenhouse effect. During this process, students worked in small groups and Robert had short discussions with each group (Observation 2, 19.1).

The teacher is observed providing feedback to the students as well as reminding them of any specific elements that should be included. He often asked students to be sure certain terminology was included in their drawings, such as “reflection”, “absorption”, “evaporation”, etc. In some cases, he was responding to student questions; such as when a student asks for clarification about evaporation, he responded by saying “Well, the heat

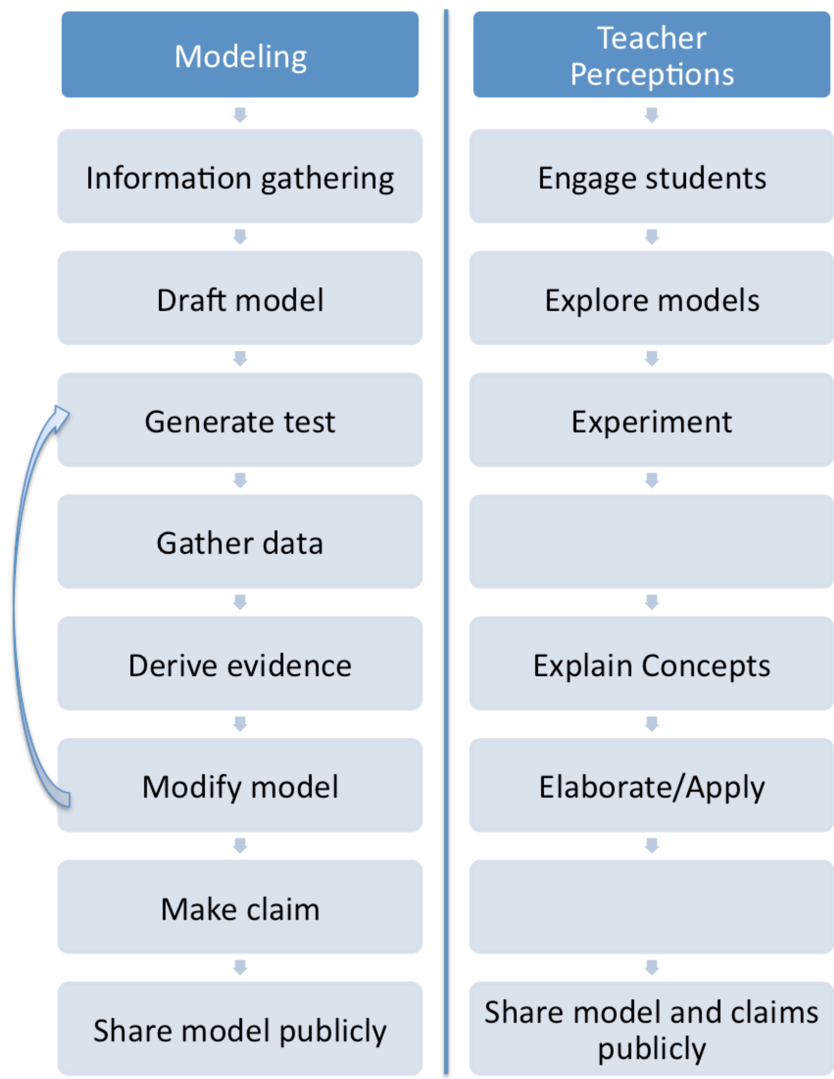

Figure 4-9 Summary of Jonathan’s observed use of argument-based inquiry, model-based inquiry, and perception of inquiry/model use.

comes from the sun, right?" (Observation 2, 25.47). In others he was providing feedback on the student's models, such as responding to student questions with an affirmative "yep!" Or by providing further information when needed (Observation 2, 19.1).

Although Robert instructed students to construct models by having them draw out the greenhouse effect, carbon cycle, and water cycle, there is no evidence that the students have the opportunity to use the models as a way to publically explain their understanding of the concept. Instead, Robert asks them to post them at the front of the room and then leads the class on a sort of whole-class discussion where the he asks the students for information and they respond. Often, responses are in the form of 1-2 words and are guesses as to what the teacher has in mind. He frequently calls on a number of students before getting the response he was looking for. Although the student-generated models are available, the teacher spends the majority of the time talking and only rarely points at one of the models, but not in a way that clearly links the model to the point of conversation. In observations, he is seen waving his hand at several of the drawings, but does appear to point at specific aspects of the drawings that associates with the concept he is verbally discussing. It is possible that the teacher's gestures are informative to himself, however it is not clear from observations that his gestures would be informative to the students (Observation 2, 30.14). Generally, these models are rarely talked about in the group conversation.

The whole class discussions that occur in Robert's class seem to be an opportunity for Robert to pass along information to his students. Although he does ask his students questions, in classroom observations he appears to be looking for a specific answer because he will accept or reject student responses. When students ask the teacher questions, he responds with information either by giving a direct verbal response (Observation 2, 8.48) or by drawing a model on the board to provide information (Observation 2, 7.57).

The dialogue that occurs in Robert's classroom is not conducive for critique and negotiation of models because student talk is generally limited to providing answers to questions or asking questions.

Melissa: Lecture to Small Group to Lecture

During whole group discussions, Melissa frequently asks her students for information, such as "what kind of energy is coming out of that light bulb?" After students responds, she generally provides feedback or follow up information, like "I would say that electrical [energy] would light it up but I wouldn't say that's what's coming out of it. [Student responds] I would say thermal is definitely a byproduct of what's going on … [student responds] there you go! Electromagnetic" (Observation 7, 12.02 & 43.43).

Many times, she clarified statements students made by rephrasing them (Observation 7, 26.53) or expanding on them (Observation 6, 5.44). At these times, the teacher is generally showing the students a model in the form of a drawing, video, or physical demonstration; she uses evidence from these models to emphasize a concept to her students by explaining the concept in detail to the students (Observation 6, 6.06).

During small group work, Melissa spends a lot of time asking students to explain their ideas (Observation 7, 26.27; Observation 11, 15.24) using the data they collected from the model-based lab experiment (Observation 11, 2.05) and reminds students that they should be discussing their ideas with each other: "I don't want to hear you answer, I want you to talk among yourselves" (Observation 6, 17.03). She frequently reminds students that their explanations should come from the data they collected, which indicates that she is expecting student explanations about the concept to come from evidence from the model. Melissa does not always rely on the model to provide evidence for the students; occasionally she will interject information to help move students towards her understanding of the concept, such as "our responding variable is the change of temperature. Everyone should be writing that down" (Observation 9, 11.17).

In general, Melissa uses a variety of techniques to pass along information to her students. She begins by asking the students for information in a whole class setting (confirming or rejecting student responses), having the students gather information on their own in a well-structured lab-based setting using models as the source of evidence, and then reminding the students what they should have learned from the lab by telling them what she thinks they should know. To assess student learning, Melissa provides students with a worksheet where they are expected to report the evidence they gathered from the lab, as well as explain in their own words what they learned from the lab.

The role dialogue plays in Melissa's inquiry/modeling approaches generally involves whole class discourse during the "brainstorming" and "asking questions" stages. Melissa provides the students with a model and asks the students to think about what is happening in the model and brainstorm ideas. The teacher does most of the talking, but she will occasionally ask a few students to share their ideas with the class. Otherwise, all ideas and explanations are usually written down in the lab report and turned in to the teacher for grading. Students share their ideas in small groups during lab. Although there is little evidence to determine whether critiquing of models occurs during these small group discussions, the teacher is often heard asking her students "why" and asking them to explain their ideas. These types of questions could lead to negotiation and critique of student ideas, but it may not necessarily lead to creation and negotiation of the model, since the evidence for student claims came directly from the model itself.

<u>Jonathan: Interacting with Small Groups</u>

In general, Jonathan asks his students very few questions while they worked in small groups; generally, he walks around and quietly observes the groups or directs them to requested supplies (Observation 19, 5.29). When the teacher does interact with groups, he is often asking them "why/how" questions like "how did you adjust the amount of absorbers?" (Observation 21, 24.27) and asking them to modify their models based on the data they collected, saying things like "If you could start from scratch, what's the one thing you would really do differently?" (Observation 21, 33.26). He will also frequently clarify student statements by restating what they said, like, "So [you are saying that] the major thing you changed was the angle [of the reflector]" (Observation 21, 38.12).

Even though Jonathan does not interact with student groups very often, observations suggest that the groups seem to hold their own conversations without probing questions from the instructor. When Jonathan does speak with a group, he generally provides them with information that is intended to improve model design. Although this provides students with evidence to better their design, it is possible that it may eliminate the need for students to discuss that aspect of their design; hence hindering depth of idea exchange. For example, in one class, students in one group were discussing how to angle the reflector of their solar cooker to maximize sunlight (Observation 13, 7.03). While discussing the pros and cons of several options, Jonathan approaches the group and gave them some specific design suggestions: "You could just try… putting construction paper there … it could start to help some" (Observation 13, 15.41). After his interaction, the students in the group did not discuss their previous design options any further; rather they sat in silence making the changes that the teacher suggested. This is one example of how this teacher goes about using dialogue to move his students toward his own understanding of the concept, which shut down the ideas students were developing for themselves.

During whole-class discussion (Observation 22, 4.31), Jonathan spent most of the time presenting information to his students, by showing them temperature change graphs, explaining the mathematical formula for solar energy, and showing them YouTube videos about sources of energy (Observation 19, 7.33). He did ask some probing questions, like "What do you think of [when you look at this graph]?" However, he also asked a lot of information-seeking questions, such as "what happens to air around the globe? Is it constantly moving or does it just stay stationary?" (Observation 17, 15.07). Additionally, student responses to his questions were usually followed up with some sort of evaluation or feedback, like "that was one of your redesign features. You actually removed that flap because it was shading" (Observation 21, 24.01). This dialogue exchange indicates that the teacher is trying to provide students with specific information that will support his understanding of the concept so that the student's understanding will eventually align with his. This type of interjection by the teacher did not support negotiation of ideas within the small groups.

After students construct, evaluate, and revise their models, Jonathan has the small groups present their design and findings to the class. Jonathan was the only teacher that specifically asked students to discuss the limitations of their models during group presentations. As students present the temperature data they collected from their solar cookers, Jonathan asks them questions such as, "was there one thing that you guys felt was the biggest factor to keeping your temperatures from getting as high as you wanted them to?" (Observation 21, 32.3). Also during these presentations, Jonathan would request that students ask the presenting group questions (Observation 21, 27.47), but would sometimes respond to student questions for the group, such as in one instance where he clarified a student's question towards one of the groups by saying, "so what he's asking is, of the equation, what is the one thing you guys really think you focused on?" Then responded on behalf of the presenting group, saying, "… sounds like they focused on the reflectors" (Observation 21, 34.20). Most frequently, the class was quiet during these presentations, and the teacher asked the majority of the questions (Observation 21, 27.49).

Based on the student talk that occurs in Jonathan's class during small group work, he generally supports student exchange of ideas by not interacting with them unless they request his attention. Most talk occurred between students within their small groups about constructing, testing, and modifying their models. When students present their models and claims to the class, there is generally very little discussion between the students. Jonathan tends to ask most of the questions that lead to critique of the models and claims. In general, there is not much evidence to indicate that critique and negotiation of models occurs during large-group discussion. And during small group discussion, teacher interjections rarely support negotiation of student ideas.

Challenges Teachers Have While Using Models

The teachers in this study express concern about the role models play in a classroom with time constraints and uncertainty about how to use models in a way that they believe best helps students learn. When asked how they would describe a science model, all the teachers struggled to respond, which could be an important factor in the challenges they face implementing models. All of them eventually resorted to providing a list of examples that they believed were models, which were all physical representations. Teachers discussed how they were useful to explain concepts, but none of them discussed the representative nature of models except for Melissa, which will be discussed in more detail later.

Since all teachers struggle to describe models as anything other than simple physical representations, it could be a factor in the challenges teachers specifically mention in interviews. Teachers expressed being worried about a) time restraints and b) how well students connect their individual conceptions with that of the model.

Time Constraints Limit Model Use

Challenges in the way of time constraints can come in a variety of forms. For Robert and Melissa, challenges are external to themselves, in that students are limited in their inquiry abilities or the teacher feels pressure from her colleagues to cover a lot of material in a short amount of time. For Jonathan, the challenges are more internal and have to do with the learning connections between the content and the models within the allotted time. Although the challenges teachers perceive vary across the three, time appears to be a consistent battle among all three teachers.

Robert expressed in an interview that his students in his class have limited prior experience with inquiry. Although he has an idea what his approach to inquiry would be in an ideal classroom, his ability to use models the way he envisions is somewhat limited since he cannot utilize inquiry to the extent he wants to. When Robert does use inquiry, it takes time to do so because his students lack experience making the necessary conceptual connections. As Robert said, “There’s not a lot of connections between thinking and doing, there is a lot of doing but not a lot of thinking” (Interview 3, 5.45). Since Robert’s students struggle to make connections between what they are doing and the concepts he is trying to convey, it would make sense to assume that the students would also struggle to make connections between a model and its associated concept.

Like Melissa, Robert tries to cover a lot of material in a short amount of time. But unlike Melissa, who feels pressure from her colleagues, Robert tends to put this pressure on himself. He appears to have high expectations of the amount of material he wants to cover during his climate unit as evident by his final project for the professional development, which was a presentation of a very extensive conceptual map that interconnected a wide variety of concepts of energy, climate, weather, and conservation. In interviews, Robert says that he implemented the climate unit into his classroom based heavily on influences received during the professional development; however, his climate unit could only extended across five class periods because the content from the rest of the semester-long course ran long. As a result, he felt that he was unable to make the majority of the connections he intended to.

Melissa feels pressure from her fellow teachers to cover a lot of content in a short amount of time, which she believes makes it impossible to do true inquiry. To use inquiry, and hence modeling practices, would take her “weeks” to cover one topic when she feels that she realistically only has “a day”. Based on her expressed limitations, she feels she needs to utilize a “more direct route” (Interview 6, 6.06) to teach content in her classroom. In an ideal classroom, Melissa said she would have the students design their own models to collect data from and make claims about the validity of the model they designed. After determining their models weaknesses, she would have them revise their models and test them again. “But I don’t have the time to do that unfortunately” (Interview 6, 00.00). As a result of this challenge, she compromises on her approach to inquiry by building models for the students rather than having them build models themselves. Melissa recognizes that this is an inherent problem, because students have their own ideas, and looking at someone else’s idea doesn’t necessarily mean that they will change theirs.

> That’s one big problem is that I have an idea of where I want them to go and I’m giving them materials hoping that they’ll see my idea. But, you know, everybody has their own idea. So that’s a challenge. (Interview 6, 19.53)

Unlike Melissa, Jonathan perceives himself to have some leeway in the content he is required to cover in his class; and unlike Robert, he feels very fortunate to have a group of students who are exposed to his inquiry approaches during their seventh grade biology class, and then again during their eight grade physical science class where he teaches his climate unit. As a result, Jonathan does not appear to be challenged by external pressures the way that Melissa and Robert do.

Although Jonathan doesn’t mention time constraints specifically when asked about the challenges he faces incorporating models into his classroom, he does imply that time limits him to some extent. He feels that he frequently has to decide between covering certain content knowledge in detail and having the students take part in an inquiry-based activity. Since Jonathan does not feel external influence to cover specific content knowledge, he makes the decision that the inquiry process will get the majority of class time. As he explains:

> I don’t get too caught up in the content. Are these kids going to remember every little fact later on down the road? No. So I

> kind of have to step back every so often and remind myself of that. It is the science skills that I'm really after, in the modeling, in the redesigning, and then in the assessing. And that's why I kind of hit the big ideas. (Interview 9, 13.12)

Robert is the only teacher that mentions management issues with relation to time constraints. As he says:

> It's always hard when you have inquiry, management-wise, when you open up projects for them to be self-guided and self-disciplined you have to constantly get them back on track…. It takes a lot of energy. (Interview 2, 0.12)

Besides taking a lot of energy, his challenge is to redirect the students during self-guided activity in order to be sure they are making the necessary connections between the model and the concept within the allotted time. To help assure that his students are making the conceptual connections between the model and the content, Jonathan tries to discuss the relationship between the solar cookers and Earth's atmosphere as often as possible, which draws students a direct link towards the big idea. He also utilizes informal assessment strategies as well as the formative assessment unit project. And he admits that next year the unit may look different from the current one, depending on student learning outcomes.

Correctly Connecting the Science Concept to Model

Teachers are concerned about how well students connect their individual conceptions with that of the model as the teacher intends them to. All teachers used models as evidence as a way to help students understand their conception of a science concept. One result of this strategy is a concern that students are not making the connections that the teachers intended them to. For Robert, students seem to miss certain aspects of the models that he feels are very clearly represented. For Melissa, models are a representation, which can lead to student misconceptions. And Jonathan's main concern was whether or not students were making connections from their models to the big idea of the unit. For the teachers in this study, all of these concerns are inherent challenges when utilizing models to teach about science content. The similarities between the three teachers indicate a concern that students may not be able to connect the science concept to the model the way that the teacher intends.

Robert said that he occasionally feels unsure that his students were able to make the connections between models and the science concept. In one case, he noticed that common misconceptions were coming up in class discussions; despite the models that they drew indicated something different. He attributes this to the students focusing on one aspect of the model, and not taking a look at the model as a whole. "Some people got too fixated on one point, but totally ignored another point" (Interview 3, 19.57). Robert believes that this is a problem because he wants his students to gather information from their models as they are drawing them. The point is to get them to "recall stuff that they should have remembered, but might not have been in the forefront of their mind" (Interview 3, 20.44). When students do not do this, Robert worries that they are developing conceptions from the models that do not align with what he intended them to develop. His approach to dealing with this issue is to provide his students with missing information during his lectures.

Melissa was the only teacher that discussed models being a representation of reality, which was a notable concern for her when using them in her classroom. She uses models to explain a concept to students so that they understand the concept the way she does. As she says, "I'm trying to hope that they get to where I want them to be [when using models]."

Melissa's main concern is that students will not understand that the model is a representation of something, and not the actual thing, which will lead them to developing conceptions that align literally with the model. As she explains:

> The whole time I'm doing this I'm thinking, ok I've got to break down their misconceptions, but not give them more… because it's so easy for a kid to come through a lab like this

> and pick up a misconception that they will not let go of for the rest of their lives. (Interview 6, 11.25)

In an attempt to avoid this, Melissa says that she likes to go over every lab with notes, encouraging her students to change the answers to their lab questions based on the information she provides (Interview 6, 12.10).

Unlike Melissa and Robert, Jonathan was concerned about how to help the students connect the big idea of the unit to the science concepts that develop as they use their models. Although he believes that students were excited about their projects and were learning about climate change issues, he was not sure how well they understood that the sun drives all energy on earth, which is connected to both weather and climate. To address this concern, Jonathan says he will attempt to draw the connections for them by telling them what he wants them to know. He believes that he as to do this because the students are either too young or too inexperienced to make the connections themselves, which is why he has to repeatedly make it for them. As he says:

> I think this is a little bit early of an age, maybe, to do some of this stuff… because they're not as educated yet on these topics, so I have to keep going back to the big ideas… there are some issues with the age I think. (Interview 2, 2.52)

Although Jonathan attributes this to the student's age or lack of experience with the subject, his, Robert's and Melissa's concerns could indicate that students are not making conceptual links between the model and the science concept the teacher intends the model to represent.

Summary

This chapter reported the results from data analysis of the three teachers who participated in this study for each research question. Firstly, teachers generally perceive models to be physical (or visual) representations of a concept, and are generally observed using those models to explain that concept and as evidence to convince students that it makes sense. Each teacher used different approaches to inquiry, thus also used models in different ways to fit with their current classroom structure, however student discussion was almost always centered around the model; such as while students created/modified models, tested models, or using models to explain an idea. Challenges teachers faced were time constraints, which made teachers feel limited in how they could use models. Teachers also expressed concern with how well students connect the concept the model represents to their conceptual understanding. Throughout the study, Jonathan stood out as an exception among the three teachers. This is most evident in Figure 4-3, where he uses models to encourage student discussion more often than Melissa and Robert. Jonathan's use of inquiry was more complete than the other participants and also aligned the best with the theoretical framework as discussed in Chapter Two, indicating that appropriate use of models may be linked to the teacher's use of inquiry.

CHAPTER FIVE: DISCUSSION

This chapter will highlight the major findings of this research study in light of current research in science education. First, there will be a discussion of each research question, beginning with teacher perceptions of using science models, how teachers use science models in terms of inquiry and dialogical approaches, and the challenges teachers face while using science models. Each of these will focus on the three characteristics of science models: that they are (1) *representations* that (2) *explain* and (3) *predict* scientific phenomenon. The chapter will conclude with implications and limitations.

Teacher Perceptions

All teachers in the study discussed using models as a part of their science units. Although teacher's perceptions of model use were focused narrowly on physical representations, such as those discussed by Gilbert et al. (2000), teachers were actually observed using a wide variety of science models, which they did not identify in interviews. These included scale, pedagogical, iconic/symbolic, and mathematical models, as discussed in Harrison and Treagust (2000). This is probably the most significant indicator that the teachers do not fully understand science models, since they are not able to recognize models when they use them. In terms of student learning, if the teachers do not recognize all forms of science models, their students will not be taught how to recognize them either. Not being able to recognize science models is an indicator that the teachers do not fully understand the characteristics of models, which is also evident from the results of this study and will be discussed further in this section.

Teachers in this study generally perceived models to be a tool for explanation. This is not an unexpected result, as pedagogical models have generally been used in science classrooms as a way to explain concepts to students (Grosslight et al., 1991; Smit & Finegold, 1995). The teachers, however, seem to indicate through both interviews and classroom observations that models can be a useful way for students to explain their ideas to each other, as well as the teacher. Given that, in general, most teachers only use models to explain ideas to their students (Edelson, 2001; Schwarz et al., 2009), the teachers in this study appear to use models as a way to encourage discussion among each other in a way that supports students explaining their ideas to their peers and to the teacher. This use of models is more effective than what teachers generally do, because having students explain their ideas is a student-centered approach to inquiry (Hand et al., 2009; Keys et al., 1999) that aligns with what is suggested in the National Science Education Standards (NRC, 1996; 2012).

Although teachers in this study perceived themselves using models to have students explain ideas to each other, their perceptions of models used in the classroom was limited to physical objects and some types of images. According to model typologies discussed by Harrison and Treagust (1998; 2000) and Gilbert et al. (2000), physical representations are the simplest forms of models, therefore teachers are generally found using them in the science classroom. To help students understand the more complex types of models, they should come to understand that all models (both simple and complex) share the same characteristics, so that they can be aware of how both complex and simple models are useful in scientific discovery.

Another important characteristic of science models is that they represent a concept or natural phenomenon. It is important to make this distinction to students so that they do not take the model literally when learning about the science concept. In interviews, Melissa was the only teacher to discuss the representative nature of models. She mentioned that she was worried the models she used in the classroom would lead to student misconceptions because students would take them literally and assume the actual phenomenon is exactly like the model, which is an important concern because it is an important characteristic of science models (NRC, 1996; 2012; Schwarz et al., 2009; Stewart et al., 2005; Windschitl et al., 2008; Harrison & Treagust, 2000; Treagust et al., 2002). However, she was not observed addressing this issue with her students, presumably because she does not know how to effectively address the issue with them. Jonathan and Robert did not discuss the representative nature of models at all, however Jonathan was observed having students design, construct, and test their own models; which according to the theoretical framework is one effective approach to implicitly address the issue of representativeness within models (Edelson, 2001; Henze et al., 2007).

Although all three teachers were observed asking their students to make predictions about certain science concepts, none of these predictions were in relation to a science model. This is consistent with results from previous studies, which suggest that teachers rarely mention that models can be used to make predictions, or observations about the natural world that are not directly observable (Justi & Gilbert, 2002; Van Driel & Verloop, 2002). Although models are a useful way to explain a complex phenomenon concisely, arguably the most important role science models play in scientific inquiry is their ability to allow scientists to make prediction, especially in climate and weather (de la Rubia & Yip, 2008). Therefore, teachers are encouraged to teach science through the use of the scientific process (i.e., inquiry; NRC, 1996; 2012) and the teachers were exposed to techniques to use models as a tool for prediction during the professional development. However, all three teachers both in interviews and during classroom observations, overlooked the predictive power of models; indicating that that they do not have a firm understanding of the role science models play in making scientific predictions. It is important that students understand the predictive power of models because science is not limited to simply explaining natural phenomenon. Without this understanding, students may perceive models as nothing more than a way to explain a science concept, which may encourage the perception that science is a body of concrete knowledge, rather than the tentative, evolving body of knowledge.

Teachers Using Science Models

Although teachers described using only a small subset of model types (e.g., Gilbert, 2011; Harrison & Treagust, 2000), each teacher was actually observed using a wide range of models. For example, Robert believes that his student drawings count as models; however, he does not discuss the laboratory set up as a type of model (flasks representing an atmosphere with various greenhouse gasses), nor does he discuss the graphs his students generated to analyze their results. Of the class time observed, Robert spent approximately 68% of the time working with models, which is the largest ratio of all three teachers in this study.

In interviews, Melissa chose to list examples of models rather than come up with a generalizable description for models. She was able to identify the majority of the models she was observed using during her unit, including drawings, laboratory exercises, graphs, pictures, videos, and three-dimensional objects (Harrison & Treagust, 2000). Melissa used the largest variety of models among the three teachers in this study. Of the observed class time, Melissa spent approximately 64% of the time working with models.

Jonathan used the fewest variety of models amung the teachers, however of the 58% class time students spent working with models, his students spent considerably more time using the models to explain ideas to each other, rather than the teacher using models to explain concepts to the students as Robert and Melissa did. Jonathan mostly used three-dimensional representations as models (which the students constructed and tested), graphs, and online videos.

In the following sections, results between each of the teachers' approach to teaching science models will be discussed in terms of (a) inquiry, and (b) dialogue.

As Forms of Inquiry

One major finding from this study is that each teacher used models within their own specific approaches to inquiry. The implication of this is that each teacher found their own way to incorporate models in their classroom without a specific approach or curriculum. Although some approaches align with the theoretical framework better than others, it is important that the teachers felt like they had freedom to use models however they perceived would fit for their teaching approaches. Robert used the fewest elements of inquiry in his classroom, yet his students spent a considerable amount of time using models; model use was not very student-centered because they were only used to obtain student's prior knowledge on the topic or explain a concept to students. Conversely, Jonathan used many elements of inquiry throughout his unit and model use was more student-centered than the other teachers, playing a role in just about every element of inquiry used. This implies that Jonathan's comfort with using inquiry in his classroom allowed for more appropriate use of science models in his classroom than the other teachers in this study, which is a very important implication of this study. For teachers to use models appropriately in a student-centered environment (such as inquiry), it may be important that they are comfortable using inquiry approaches before they are asked to utilize models appropriately.

Even though every teacher had his or her own approach to inquiry, some similarities did emerge. All teachers used models as evidence to help students understand a science concept the way the teacher understands it; which is what research tells us about how most teachers usually use models in the classroom (Schwarz et al., 2009; Edelson, 2001), hence this result was not suprising. However, teachers were rarely observed asking students to make predictions based on the science models and/or evaluate science models, which is an important way for students to understand science models (Edelson, 2001; Henze et al., 2007; Schwarz et al., 2009), especially when using a student-centered approach to learning, such as inquiry.

Although teachers had their own approaches to using models within inquiry approaches, two of the three teachers felt restricted in their ability to use inquiry to the extent they would like to. Therefore, Robert and Melissa explain how models would be used in an ideal situation as well, which gives insight as to how their perceptions of inquiry align with the theoretical framework and classroom observations. Jonathan is the exception to the case, stating that he was able to use inquiry freely in his classroom, so he utilized it consistently. It becomes evident that a teacher's ability to use inquiry impacts their ability to use models within a student-centered approach, which is best for student learning about models (Edelson, 2001; Henze et al., 2007; Schwarz et al., 2009; Windschitl et al., 2008).

In his ideal classroom, Robert explained that he would ask students to develop their own procedures to answer a question. However, Robert feels that his students are generally very inexperienced and needed more guidance that he felt inquiry would allow. Therefore, he included students in the learning process by eliciting information from them during class lectures and having them draw representations of scientific concepts, including the water cycle. Based on his perceived limitations, Robert uses only a couple of elements of inquiry throughout his unit. Of the teachers in this study, Robert's observed and perceived approach to inquiry had the fewest elements as compared to that from the theoretical framework, making his classroom less student-centered than the other teachers in this study. It is possible that since Robert's perception of ideal inquiry was fairly limited and incomplete, it translates into his modification of inquiry as well. Therefore, his use of models was also limited to one specific aspect of inquiry, as well as in the three characteristics of models, focusing on only using models to explain ideas to students. The representative nature and predictive power of models was not addressed in Robert's classroom.

Melissa also felt restricted in her ability to use inquiry because she is expected to align her lessons with those of the other ninth grade science teachers at her school. In her ideal classroom, she would ask students to develop a procedure to test their own conceptual understanding of a topic, then have them revise their test based on findings. However, she is expected to cover a certain amount of material in a certain amount of time using the same assignments and lab assignments as the other teachers in her school. Therefore, she feels that it is necessary to establish a procedure for her students and ask them to explain their ideas, asking for written responses in the labs, as well as oral responses during small group and whole-class conversations. Her ideal and observed use of inquiry had a few elements of inquiry from the theoretical framework, but the significant difference between the student-centered approach in her classroom and Robert's classroom was seen in the modeling. She was observed using models to ask students for current conceptions on a topic, to support or challenge a students current conception on a topic, and emphasize the teacher's understanding of a concept to the students; all of these uses is how science models are usually used in the classroom (Schwarz et al., 2009; Edelson, 2001), but it includes students explaining ideas to each other and themselves using models, not just the teacher using models to explain ideas to the students. Since Melissa had a more developed idea of an ideal approach to inquiry than Robert did, her use of models was more student-centered and included a more effective use of one of the characteristics of modeling. The representative nature and predictive power of models was still not addressed in Melissa's classroom.

Jonathan is the only teacher in the study who does not feel external pressure to limit his use of inquiry in the classroom and, interestingly, is also the teacher who incorporated the most elements of model-based inquiry from the model in the theoretical framework. He clearly states that he uses the 5E approach to inquiry in his classroom (Bybee et al., 2006), which he uses to engage students in science-oriented questions. For his climate unit, he challenged students to construct the best possible solar cooker using only recycled material. He asked them to come up with their own designs, test variable, procedure, and evaluation methods, which is an effective approach to model-based inquiry because the students were asked to create their own models based on their own understanding of the concept (Schwarz et al., 2009; Edelson, 2001); then students shared their revised designs and results with their classmates during whole-class discussion.

Although his classroom included a more complete version of inquiry and was the most student-centered of all the teachers in this study, his use of models was limited in the same way Melissa's use was limited. In other words, he used models to explain ideas to students and have students explain ideas to each other, but the representative nature and predictive power of models was not addressed in his classroom either.

Although each teacher in the study had different approaches to inquiry that involved more or less effective approaches to using models, two characteristics of models were consistently overlooked; the representative nature and predictive power of models. Since teachers did not address these two characteristics in interviews or during observations, it is clear that they do not fully understand the role models play in the scientific process, which should be addressed in future studies.

Elements of Dialogue

Regardless of the way Robert and Melissa's classroom discussion was designed, the models play a role of gathering student prior knowledge and act as evidence for teachers to explain a concept to their students. The way Robert and Melissa used models is not unlike the way most teachers generally used science models (Schwarz et al., 2009; Edelson, 2001; Windschitl & Thompson, 2006).

Again, Jonathan is the exception. Although models seem to serve as a way to explain concepts to students in his classroom, they also appear to be frequently used as a way for students to explain ideas to each other; this is a less common, infrequently observed use for models in most classrooms, particularly because Jonathan has students construct their own models instead of using preconstructed ones (Windschitl & Thompson, 2006). Therefore, results indicate that the role models play in argumentation in Jonathan's classroom is more student-centered than the role models play in Robert's or Melissa's classrooms (Schwarz et al., 2009; Edelson, 2001).

Even though Jonathan's classroom focuses on the 5E approach to inquiry (as opposed to argument-based inquiry), a fair number of elements of both argument- and model-based inquiry were evident in his classroom. This is an important finding that suggests that since the teacher is oriented within the philosophical framework of an approach to inquiry, elements of the approach to inquiry, as described within the framework introduced in Chapter Two, emerged in his classroom even though he did not specifically use that framework. In this instance, argument-based inquiry, model-based inquiry, five essential features (NRC 1996; 2012), and the 5E model all appear to be aligned with each other, assuming the teacher uses each approach appropriately.

Even though dialogue looks different in each teacher's classroom, all teachers in this study used models as a central topic of dialogue among their students. Regardless of whether teachers were asking students for ideas or sharing ideas with the students, the teachers used models to guide discussion among students towards the teacher's conception of the scientific phenomenon. Research indicates that using the models as a focal point during student conversation is more student-centered than traditional classroom uses of models (Schwarz et al., 2009; Edelson, 2001; Henze et al., 2007), therefore this aspect should be emphasized when preparing teachers to use models in the science classroom. As stated earlier, it is common for teachers to use models as a way to explain a concept to students. However, it is less common, but important, that students have the opportunity to discuss the concepts represented in the model because student discussion is an important element of learning within an inquiry environment (Driver et al., 2000; Duschl & Osborne, 2002; Fischer, 1995; Hand et al., 2009; Keys et al., 1999; NRC, 1996; 2012; Yore & Treagust, 2006).

Robert used models as a way to generate small group discussion about a concept. He asked his students to work in small groups as they drew representations of the water cycle and the greenhouse effect, where students discussed the concepts with students in their groups as well as students in other groups, which the teacher supported. Robert saw the dialogue between students as an opportunity for them to remind each other of terminology or elements of the process that they may have forgotten from prior class work or the reading assignment. He does not seem to think that student learning of the concept occurs during the discussion, although according to research it actually can (Driver & Oldham, 1986; Driver et al., 2000; Duschl & Osborne, 2002; Hand et al., 2009; Keys et al., 1999; Osborne et al., 2004; Posner et al., 1982). This is an important aspect that is missing from Robert's understanding of inquiry, indicating that he does not have an adequate grasp on inquiry, because all approaches to inquiry involve some aspect of argumentation for student learning (Bybee, 2006; Keys et al.,1999; NRC, 1996; 2012; Windschitl & Thompson, 2006). Teachers should understand the argumentation aspect of inquiry because it will lead to more effective use of inquiry, but also more effective use of science models, because argumentation is a key aspect of the role models play in the scientific process (de la Rubia & Yip, 2008; Edelson, 2001; Henze et al., 2007; Windschitl et al., 2008).

Similarly to Robert, Melissa asks students to work in small groups collecting data from models before reinforcing the information with a lecture. Rather than have students create their own models, which would be best for student learning (Schwarz et al., 2009; Edelson, 2001), Melissa provides the students with a specific procedure to build and test physical models in a way that provides the students with evidence to support her own conception of the phenomenon. As a part of her procedures, she asks students to explain their observations to each other and to make claims about how the phenomenon works, indicating through interviews that she believe it helps the students think critically and learn to problem solve. Unlike Robert, this shows that Melissa believes that students do learn during conversation, which indicates a better understanding of inquiry and the role argumentation plays in student learning. Models, however, were only used as a focal point for conversation among students; there was no discussion about the included evaluation of the model or the different possible explanations that can come from the model. These kinds of discussions are important to help students understand the representative nature and predictive power of models (Edelson, 2001; Henze et al., 2007). Since this aspect of modeling is still lacking, even during student argumentation, it indicates that the teacher is not familiar enough with the characteristics of science models to teach it effectively.

Jonathan does not use lectures the same way Melissa and Robert do. Rather, Jonathan provided his students with information periodically throughout the unit that he believes should help them with their model-building assignment, essentially only providing them with information they might need when he thinks they need it. This approach is an effective way to help students construct knowledge, according to Posner et al. (1982). The majority of class time is spent having the students design, construct, test, and revise solar cookers; which is an approach to having students evaluate and revise models (Edelson, 2001; Schwarz et al., 2009). Students work in small groups, so most discussion occurs within the small groups as they work on the design of their models, giving them opportunity to share ideas and come to understand the role science models play in science (Edelson, 2001; Henze et al., 2007). In this instance, there is evidence that Jonathan's students are exploring the representative nature of models. However this is an implicit approach since Jonathan never explicitly refers to their solar cookers as models, nor does he mention that models are representations of a phenomenon and not the actual thing. The predictive power of models is still not addressed throughout Jonathan's approach.

It is important to note that although Jonathan's approach to inquiry and modeling implicitly lead to better coverage of the three characteristics of modeling, these were implicit and does not suggest that Jonathan has a better understanding of science models than Melissa or Robert. A more complete use of inquiry happened to lead to better coverage of the characteristics of models, however studies are still needed to explore how well students understand these characteristics of models as a result of learning through these implicit methods.

Challenges Teachers Face

All teachers in the study expressed some difficulty using models within a reasonable time constraint, as well as concern with their students' ability to make meaningful connections between the science models and the concept the model represents; which, according to Harrison and Treagust (2009), is a very difficult thing for students to do. However, with appropriate use of models within inquiry, it is theoretically possible for students to make these connections (see Chapter Two). However, it does require that the teacher understand and be invested in proper use of inquiry as well as the role models play in authentic science. Results from this study indicate that some teachers do not fully understand inquiry and none of the teachers have a complete understanding of science models; which are an important part of understanding the challenges teachers face when it comes to teaching with science models.

The first common concern among teachers was that they felt restrained by time limitations within their classroom. Jonathan had fewer concerns with the time constraints than Robert and Melissa did. Robert and Melissa felt restricted by external factors to use inquiry to the extent they wanted to in their classrooms. Both teachers expressed that incorporating inquiry was the more difficult task to incorporate than the use of models. Teachers frequently express concern using inquiry within the confines of a traditional classroom, however the only aspect of modeling that was consistently used among all teachers was to foster explanations of a concept, which is what models are most commonly used for in the classroom anyway (Edelson, 2001; Schwarz et al., 2009). Since inquiry was seemingly difficult for these teachers to incorporate, it is not surprising that they also had some issues incorporating all aspects of modeling into their unit as well. This indicates that there is still a need to support pre-service and in-service teachers as they attempt to utilize inquiry effectively when there are external restrictions on their classroom time.

Jonathan, on the other hand, only felt limited with his time because he felt he needed to choose between covering content and having the students do inquiry to the extent he wants; though he explains that he always prefers to have students do science over learning content because he feels the inquiry is more important for the students long-term than specific content knowledge, which is the preferable choice (NRC, 1996; 2012). However, even though his inquiry approaches were more complete than the other two teachers, his use of models was also generally restricted to using them as a tool to explain a science concept. Like the other two teachers, there was little to no discussion or application of the other characteristics of science models. Hence, it is still important that teachers are educated in the concept of science models and the role they play in science discovery.

Explicit discussion of the role models play in inquiry is also necessary for teachers to use and teach models effectively in the classroom (Justi & Gilbert, 2002). As discussed earlier, teachers both described and were observed using models as a way to explain a concept to the students, however it is also important to emphasize that models are representations and can be useful tools for making predictions (Edelson, 2001; Henze et al., 2007). None of the teachers discussed or were observed using models to make scientific predictions, and only Melissa discussed the representative nature of models, but only in interviews; she did not bring up the issue with her students. In interviews, she expressed concern about student's ability to recognize that models were representations of a science concept, and not the literal object, which is a common issue that has been discussed in previous research (e.g., Harrison & Treagust, 2000; NRC, 1996; 2012; Schwarz et al., 2009; Stewart et al., 2005; Treagust et al., 2002;Windschitl et al., 2008). She recognized that students who consider the model literally may end up with new incorrect conceptions rather than the one she is trying to convey. Since the representative nature of models and their use to make predictions is being overlooked in these classrooms, it is an indicator that the teachers either do not recognize those characteristics of models or do not know how to adequately address them within the classroom. As stated earlier, this is a problem that should be addressed during pre-service and in-service education by making the link between science models and inquiry explicit (Penuel et al., 2007). Also, teachers need more time working with and experiencing models within an inquiry environment (such as that of authentic research) because they will be better informed to use models effectively within their own classrooms as well (de la Rubia & Yip, 2008; Penuel et al., 2007; Windschitl et al., 2008).

According to classroom observations, none of the teachers' approaches to using models aligns very well with the theoretical framework, which they were exposed to in the professional development. Although teachers were not expected to follow the framework explicitly, teachers who teach within the paradigm of the five essential features of inquiry (NRC, 1996; 2012) and use science models effectively (e.g., Edelson, 2001; Henze et al., 2007; Windschitl et al., 2008) should have an approach to model-based inquiry that looks similar to the theoretical framework. While comparing classroom observations with the theoretical framework, at least a couple elements of model-based inquiry were evident in each classroom; no new or unexpected elements were identified. However, it is important to note that Jonathan's approach had the most elements of model-based inquiry of all the teachers. Jonathan used inquiry prior to incorporating models and does not feel external pressure to limit his use of inquiry the way Melissa and Robert do, therefore it is not surprising to observe several elements of inquiry in his classroom. Additionally, he was the only teacher to mention that he believes it is most useful that students leave his class with an understanding of the nature of science than with specific content knowledge, which indicates that his teaching philosophy aligns well with the paradigm of the five essential elements of inquiry (NRC, 1996; 2012). This may explain why he was the only teacher to use science models in an effective, student-centered way, such as that described by Edelson (2001), Henze et al. (2007), and Windschitl et al. (2008). Therefore, teachers should not just be taught how to use science models in the classroom, their perspective on science education should be oriented towards an inquiry-approach paradigm (e.g., Fischer, 1995; Keys et al., 1999; Hand et al., 2009; NRC, 1996; 2012; Posner et al., 1982).

Implications

Teachers in this study used models as a way to explain concepts to their students. However, teachers did not convey that models are representations and they did not use models as a way to make scientific predictions. Therefore, the teachers either do not understand those two aspects of modeling as defined by Schwarz et al. (2009), or they do not know how to convey those aspects to their students. In order for teachers to use science models appropriately in the classrooms, teacher education needs to focus on those aspects of modeling as well as how to convey them to students effectively. This is not just important to help students understand science models, but also to understand the nature of science (Justi & Gilbert, 2002; Lehrer & Schauble, 2004; Schwarz et al., 2009; Stewart et al., 2005) because it helps students understand the stable, but tentative nature of scientific concepts.

The major argument made in Chapter Two is that model-based inquiry is the same process as argument-based inquiry, which are both structured around the five essential features of inquiry. Therefore, it can be said that since Jonathan was already comfortable and experienced using inquiry in his classroom, he had an easier time incorporating models appropriately; which is why he stood out as a contrast case among the other teachers in this study. The implication of this result is that teachers who want to incorporate modeling into the science classroom may have an easier time doing so if they are already oriented towards an inquiry approach paradigm.

This research has implications for teacher education as well. Assumptions made in the theoretical framework were that teachers who would participate in the study were already comfortable with some approach to inquiry in order to incorporate modeling effectively. However, in order for teachers to use inquiry effectively, they must have a perspective on teaching science that aligns with the five essential features of inquiry (NRC 1996; 2012), and/or Posner et al.'s (1982) theory of conceptual change. Both of these philosophical views on learning emphasize the importance of understanding the scientific process, verses a focus on passing along specific content. Studies that look at teachers who use argument-based inquiry suggest that it takes time and persistence with inquiry for teachers to change their current understanding of teaching science from a content- to process-based knowledge. Martin and Hand (2009) estimate that conceptual transformation takes teachers approximately 18 months. Since the professional development only exposed the teachers to model-based inquiry for a week, it is not surprising that the participants in this study did not fully understand the characteristics of science models and the role they play in inquiry. Others studies that seek to increase teacher understanding of science models was met with similar findings (Windschitl & Thompson, 2006). For model-based inquiry to be implemented effectively, teachers will need to be exposed to it and practice it consistently for an extended period of time. Therefore, it is most important that teachers are exposed to model-based inquiry during their teacher training programs because then they will have the time and opportunity to orient their thinking, whereas in-service teachers will have limited opportunities for lengthy, ongoing professional development (e.g., Hand et al., 2009).

Finally, this study focused on teacher understanding and use of science models in the classroom. Students were not involved in this study beyond the observations of how the teacher interacted with them. This means that student learning was not considered as a part of this study. Regardless of how the teachers understand and teach modeling and model-based inquiry, eventually student learning becomes the most important outcome of using the approach. Since there are very few studies that look at how teachers implement modeling into the classroom, it was important to consider this aspect before looking at student learning. Future studies should begin to analyze how student learning is impacted by various approaches to model-based inquiry.

Limitations

One limitation of this study is that a detailed analysis of the participants was chosen in order to do a more detailed analysis on fewer teachers rather than a more general analysis on several teachers. Therefore, the findings of this study cannot be generalized towards a larger population of teachers. However, the detailed analysis does provide some important findings that provide insight as to how teachers use models within an inquiry environment and what limitations may be present that prevent teachers from using them effectively.

Teachers in this study were specifically oriented towards one approach to model-based inquiry through a professional development course. Therefore, findings have been oriented towards the concepts and understanding of models that these specific teachers were exposed to. Findings do not represent a teacher's general understanding of science models and likely will not apply to teachers who participate in other types of professional developments.

Finally, data for this study was gathered using interviews and classroom observations, so information provided by the participants were given directly to the researcher and not through truly anonymous means. As a result, it is possible that the information provided by the participants was not truthful in an attempt to appease the researcher or improve their appearance in the eye of the researcher. Although steps were taken to develop rapport with the participants, it cannot guarantee truthful responses from all the participants in all cases.

Summary

This chapter summarized the contributions of this study to the scientific community. Teachers in this study showed a lack of understanding about the characteristics and use of science models, which limited their ability to teach about the concept of modeling fully. However, there was evidence that models could be used appropriately in the classroom if the teacher is comfortable with inquiry and able to use it the way they want. Future work should look at how to improve teacher understanding of models as well as student learning from using models in an inquiry-based environment.

APPENDIX A: DETAILED AGENDA FOR THE PROFESSIONAL DEVELOPMENT

Monday

8:00 - 8:30	Welcome and Introductions
8:30 - 10:00	Introduction to science models
10:00 - 10:15	Break- Fill out registration forms
10:15 - 11:15	Energy Basics seminar
11:15 – 12:00	Make Individual Posters about current unit concept flow, lesson plans, teaching strategies, and innovations.
12:00 - 1:00	Catered Lunch & Simultaneous “Poster Session”
1:00 – 1:45	Energy seminar
1:45 – 3:30	Energy transfer activity and modeling changes of state.
3:30 – 3:45	Break
3:45 – 4:30	Form small groups for collaboration on unit innovation
4:30 – 5:00	Reflection and Feedback

Tuesday

8:00 – 12:00	Fieldtrip: Turbine Manufacturer; tall tower
12:00 - 1:00	Lunch (on your own)
1:00 – 1:30	Field trip Reflection
1:30 – 2:00	Presentation and group sharing of online or packaged curricular modules available for energy topics.
2:00 – 3:15	Seminar on global circulation and embedded activity
3:15 – 4:30	Project work time
4:30 – 5:00	Reflection and Feedback

<u>Wednesday</u>

8:00 - 10:15	Mystery Tubes- Guest speaker
10:15 – 11:15	Climate impacts in the state of Iowa - Guest speaker
9:30 – 10:30	Seminar on Climate, Weather, and the water cycle
12:00 – 1:00	Lunch (on your own)
1:00 – 1:30	Presentation of online or packaged curricular modules available for weather topics.
1:40 – 3:30	Fieldtrip- power plant
3:30 – 4:00	Reflection on power plant tour
4:00	Adjourn for the afternoon session.
5:00 – 6:15	Group dinner with guest speaker
6:30 – 8:00	Weather Forecasting: Guest speaker

<u>Thursday</u>

8:00 – 11:00	Greenhouse gasses: activity and seminar – Guest speaker
11:00 – 12:00	Potential game changing ideas in the energy landscape
12:00 - 1:00	Lunch (on your own)
1:00 – 2:00	Uncertainty and Ensemble Modeling- Guest Speaker
2:00 – 3:45	Climate Modeling Activity- Guest speaker
3:45 – 4:00	Reflection and Feedback
4:00 - 5:00	Project work time

<u>Friday</u>

8:00 – 8:30	Discussion of research
8:30 – 9:00	Course Evaluation Survey
9:00 – 10:15	Project work time
10:15 – 10:30	Break; Setup panel presentations
10:30 – 11:15	Project discussion and feedback: Panel 1

11:15 – 12:00	Project discussion and feedback: Panel 2
12:00 – 1:00	Lunch (on your own)
1:00 – 1:45	Project discussion and feedback: Panel 3
1:45 – 2:30	Project discussion and feedback: Panel 4
2:30 – 2:45	Break
2:45 – 3:30	Project discussion and feedback: Panel 5
3:30 – 3:45	Discussion of future activities
3:45 – 4:30	Reflection and Feedback
4:30	End of on campus portion

APPENDIX B: INTERVIEW PROTOCOL

Interview protocol used during data collection for all three participants in the study. Note that not all questions were asked during the interview process. Follow up questions were asked based on the responses the participants gave to key interview questions.

Reflective Interview Protocol:

- In general, how do you feel your unit is going [or how did it go]?
- Please describe how you generally plan to use science models in your unit.
- In what way do you think the models helped your students learn the content, if at all?
- What do you hope your students will learn from using the models?
- What do you think has been going well so far? Why?
- What do you think you will change next time? Why?
- What was the most difficult aspect of teaching this unit using models for you?
- Do you think it's possible for students to build their own models? Why or why not?
    - What do you think your students will talk about when they are working with models?
    - How do you intend for students to interact with each other while using models?
- In your opinion, what is inquiry?
    - Do you think using models will enhance the inquiry process for your students? Why or why not?
- What do students talk about when they are working with models? How do they interact with each other?

Pre- and Post-unit Interview Protocol:

Key Interview Questions

- Please describe how you generally plan to use science models in your unit.

- In what ways do you think the use of the models would support student science learning?
- What do you hope your students will learn from using the models?
- In what way did the models you use help your students learn the content? What are some ways you felt the models didn't help the students learn?
- Do you have any concerns with the upcoming unit? What are they?
- What went well with your unit and why? What didn't go well and why?
- What do you think you will change next time and why?
- What was the most difficult aspect of teaching this unit using models for you?
- Would you like to use science models more frequently in the future? Why or why not?
- Would you like to suggest other science teachers to use models in their instruction? Why or why not?

Sub-Questions: Inquiry

- In your opinion, what is inquiry?
- What elements of inquiry do you intend to use?
- Do you think using models will enhance the inquiry process for your students? Why or why not?
- Do you expect your students will ask different kinds of questions while using models? If so, what do you expect to be different?
- Do you intend to use models as a way to help students work with claim and evidence? If so, how?
- Will students be evaluating science models in some way? If so, how do you plan to facilitate that process?
- What kinds of predictions will the students be making while using science models?

- Were the students making predictions while using science models? How do you think that went?

Sub-Questions: Dialogue

- What do you think your students will (do) talk about when they are working with models?
- How do you intend for students to interact with each other while using models?
- How do the students interact with each other while working with models?
- Do you notice the pattern of conversation with your students being different while using models than during other group activities? If so, how? If not, how are they similar?
- What kinds of conversations do you expect students to have?
- What do students talk about when they are working with models?

Sub-Questions: Types of Models

- In your opinion, what is a science model?
- What are some examples of science models you plan to use?
- What made you decide to use these models?
- If students will be creating their own models: what kind of support do you plan to give your students?
- Do you think it's possible for students to build their own models? Why or why not?
- I noticed you used this model today [describe model] why did you decide to use that one?
- How well did your students develop their own models?
- How did you facilitate the model building process?
- How well do you think using/constructing the models helped students understand the science concepts?

Table B-1 Justification of the data sources and interview protocol by research question.

Research questions		What do I need to know?	Major interview questions
What are teachers' perceptions of how the use of models support student learning in the science classroom?	*In terms of Inquiry approaches*	How important do they think questions are in the learning process? How do they think claims and evidence from models contribute to student learning? How do they think students can use models to evaluate claims and evidence effectively? How do they think models can be used as a predictive tool?	Please describe how you generally plan to use science models in your unit. What do you hope your students will learn from using the models? *Sub-questions: Inquiry* What elements of inquiry do you intend to use? Do you think using models will enhance the inquiry process for your students? Why or why not? Do you expect your students will ask different kinds of questions while using models? If so, what do you expect to be different? Do you intend to use models as a way to help students work with claim and evidence? If so, how? Will students be evaluating science models in some way? If so, how do you plan to facilitate that process? What kinds of predictions will the students be making while using science models?
	In terms of elements of dialogue	How do they believe idea exchange should occur? What interactions do they think are their students should have with each other? What do they think conversation patterns should look like?	*Sub-questions: Dialogue* What do you think your students will talk about when they are working with models? How do you intend for students to interact with each other while using models? What kinds of conversations do you expect students to have?
	Types of models used	What kinds of models do they plan to use? Where do these models come from? To what extent do they think students can create their own models?	*Sub-questions: types of models* What are some examples of science models you plan to use? What made you decide to use these models? If students will be creating their own models: what kind of support do you plan to give your students? Do you think it's possible for students to build their own models? Why?

Table B-1 Continued.

How do teachers use models to support student learning in the science classroom?	*In terms of Inquiry approaches*	What kinds of questions do they ask? How do they use models to support development of claim and evidence? How do they encourage students to evaluate models? How do they utilize models as a tool for prediction?	In general, how do you feel your unit is going [or how did it go]? In what way did the models you use help your students learn the content? What are some ways you felt the models didn't help the students learn? *Sub-questions: Inquiry* What elements of inquiry do you intend to use? Do you think using models enhances the inquiry process for your students? Why or why not? Do you think your students used models to generate claims and evidence? If so, how? How well do you think your students evaluated science models? Were the students making predictions while using science models? How so?
	In terms of elements of dialogue	How does idea exchange occur? What interactions do they encourage students to have with each other? What do conversation patterns look like?	*Sub-questions: Dialogue* What do students talk about when they are working with models? How do the students interact with each other? Do you notice the pattern of conversation with your students? Please explain.
	Types of models used	What kinds of models do they use? Where do these models come from? To what extent do they allow students to create their own models? How well do they understand the concept of modeling?	*Sub-questions: types of models* I noticed you used this model today. Why? How well did your students develop their own models? How did you facilitate the model building process? How well do you think using/constructing the models helped students understand the science concepts?

Table B-1 Continued.

What challenges do teachers have implementing models into their classroom?	How well do they understand the concept of inquiry?	Do you have any concerns with the upcoming unit? What are they? What went well with your unit and why?
	What parts of their units are they concerned about and why?	What do you think you will change next time and why? What was the most difficult aspect of teaching this unit for you?
	What challenges do/did they anticipate having while teaching the unit?	In your opinion, what is inquiry? In your opinion, what is a science model?

APPENDIX C DETAILS OF DATA SOURCES AND IDENTIFIERS

Table of data sources and the code used to identify each source.

Teacher	Data Source	Date	Identifier
Robert	*Interview*	January 20, 2012	Interview 1
		February 1, 2012	Interview 2
		March 1, 2012	Interview 3
	Observations and field notes	December 8, 2011	Observation 1
		December 12, 2011	Observation 2
		December 13, 2011	Observation 3
		December 14, 2011	Observation 4
		December 16, 2011	Observation 5
Melissa	*Interview*	October 27, 2011	Interview 4
		October 28, 2011	Interview 5
		March 5, 2012	Interview 6
	Observations and field notes	October 27, 2011	Observation 6
		October 28, 2011	Observation 7
		February 23, 2012	Observation 8
		February 24, 2012	Observation 9
		February 29, 2012	Observation 10
		March 5, 2012	Observation 11
	Document	October 27, 2011	Document 1
		February 10, 2012	Document 2
		February 29, 2012	Document 3
Jonathan	*Interview*	January 27, 2012	Interview 7
		February 10, 2012	Interview 8
		February 27, 2012	Interview 9
	Observations and field notes	January 27, 2012	Observation 12
		February 01, 2012	Observation 13
		February 2, 2012	Observation 14
		February 3, 2012	Observation 15
		February 6, 2012	Observation 16
		February 9, 2012	Observation 17

	February 10, 2012	Observation 18
	February 15, 2012	Observation 19
	February 16, 2012	Observation 20
	February 23, 2012	Observation 21
	February 27, 2012	Observation 22
Document	January 27, 2012	Document 4
	February 1, 2012	Document 5
	February 3, 2012	Document 6
	February 3, 2012	Document 7
	February 27, 2012	Document 8

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