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# The Development of a Performance Progression for Science Teachers' Implementation of Model-Based Teaching

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THE DEVELOPMENT OF A PERFORMANCE PROGRESSION FOR SCIENCE  
TEACHERS' IMPLEMENTATION OF MODEL-BASED TEACHING

by

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## DEDICATION

This dissertation is dedicated to my family Tina, Alyssa and Nicholas. Without their support and patience, this would not have been possible. Thank you.

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Over the past seven years, there have been many people from whom I have received support and encouragement. Dr. Christine Lotter, my advisor and mentor, was immensely supportive throughout my journey. My former high school administrator, Joyce Jackson, provided me with the flexibility I needed to grow as a teacher as well as develop my skills as an education researcher. I am immensely grateful for their patience and professional support.

As a teacher, I was fortunate to have some of the best, brightest, and most considerate students in my classroom. They always had faith in me that the instructional strategies I was “experimenting” with would be fruitful and productive. When it came time to for me to run a professional development institute, my students provided the leg work, manual labor, and organizational skills to keep the institute running smoothly. I specifically thank Emily Rhorick for her dedication throughout that long week in the summer of 2012.

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Along the way, I changed careers, moving from the classroom to a position leading teacher professional development. My colleagues at the Knowles Science Teaching Foundation kept me motivated and provided insights and advice through one of the most challenging years of my life, both personally and professionally. For their help and advice, I am eternally grateful.

Through the years, many family members supported my journey with babysitting, tuition bills, and emotional support. My grandmother in-law Lillian, mother in-law Barbara, and Father in-law Doug spent countless hours looking after my son while I worked in the office or at the local coffee shops. My mother Adele, my father Nick, and my second father Jim helped me keep “the faith” in myself and my work. From these family members, I drew strength. Thank you, all of you, for your support and guidance through this journey.

And last and most importantly, I thank my wife, Tina. Without your patience and perseverance in holding our family together and reminding me of why I am doing this work in the first place, well, no words can really do justice to the incredible spirit and immense love that you shared along the way.

## ABSTRACT

The Next Generation Science Standards (NGSS) call for science teachers to implement pedagogical strategies that can approximate authentic scientific practices. One such strategy, Model-Based Teaching, engages students in learning the disciplinary core ideas of science through the process of developing and using Scientific Models. Model-Based Teaching is a difficult pedagogical strategy for teachers to learn and implement. Factors such as Knowledge of Scientific Models and Modeling (KSM), understanding of the Nature of Science (NOS), and use of questioning to facilitate whole class discussions play important roles in the development of teachers' ability to implement Model-Based Teaching. This study employed a mixed methods, multiple case study approach to investigate the impact these factors had on in-service science teachers' ability to implement Model-Based Teaching. Data from before, during and after a one-week summer professional development institute that focused on Model-Based Teaching were collected and analyzed for 15 middle and high school science teachers. Three of these teachers were selected for a multiple case study. Through the use of the Interconnected Model of Teacher Professional Growth (IMPG) (Clarke & Hollingsworth, 2002) as an analysis framework, a performance progression for Model-Based Teaching was identified. This performance progression identified four distinct levels of Model-Based Teaching including Pre-Modeling, Emergent Modeling, Transitional Modeling, and Adept Modeling. Three of the four levels are exemplified through the case study teacher descriptions. Teachers' questioning skills, knowledge of models, and understanding of

the nature of science, were found to be important factors in the progress of science teachers towards effective implementation of Model-Based Teaching. Facilitating whole class discussions focused on models was found to be a central factor in the progression of teachers' implementation of Model Based Teaching. Implications for professional development of science teachers include a need to provide sustained experiences that build knowledge of scientific models and modeling as well as support student-centered discourse strategies that focus on the use of questioning to facilitate whole class discussions.



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## CHAPTER 1

### INTRODUCTION

In 1910, John Dewey published *How We Think*, which contained in it an outline of what we know today as The Scientific Method (TSM). This ultimately redefined how most people thought of science and its application as an everyday problem-solving activity (Rudolph, 2005). Since then, TSM has come to be the predominant, almost exclusive, view of science that has been taught to American students. Yet as far back as the 1950's, scientists have criticized its use as the only method of science being described to school children (Windschitl, Thomson, & Braaten, 2008). They argue that TSM resembles a very small portion of the work scientists do and many instances of science can be identified that use little or none of TSM described in schools.

Cold war era anxiety and the "Space Race" in the late 1950s inspired the nation to develop and enact science education reforms aimed at improving American students' ability to do science and think scientifically. A subsequent reform movement in the 1980's culminated with the release of the Benchmarks of Science Literacy (AAAS, 1993) and the National Science Education Standards (NSES) (NRC, 1996). Both documents were unanimous in their call for science educators to teach in ways that reflect the generally accepted view of the Nature of Science (NOS) as well as engage students in the processes of science in a more accurate and authentic way.

The NSES provided standards for teaching, professional development, assessment, content, science education programs, and science education systems. They

provided all of these standards in order to realize the systemic change being called for through the movement from didactic teaching to an inquiry based approach. “Inquiry” teaching not only engages students in the processes of science but also allows for the development of the understanding of science content through engagement in these processes (AAAS, 1993, p. 9; NRC, 1996, p. 105). Inquiry is highly regarded as a successful way to teach students about the nature and process of science while also teaching them the content of science.

The NSES standards are organized into 8 categories which are further subdivided into concepts which students need to develop understanding in three different grade bands; k-4, 5-8, and 9-12. Within each category there range from two to six indicators of what students should know at each grade band. These indicators are further subdivided into descriptions of “fundamental concepts and principles” that underlie the standard.

As a follow up publication to the National Science Standards, the NRC published *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*, (2000). In it, the National Research Council expanded on the continuum that was discussed in the original standards and identified five essential features of classroom inquiry that could be identified in any quality inquiry activity regardless of the specific implementation strategy. They included:

- “Learner engages in scientifically oriented questions”.
- “Learner gives priority to evidence in responding to questions”.
- “Learner formulates scientific knowledge”.
- “Learner connects explanations to scientific knowledge”.
- “Learner communicates and justifies explanations” (NRC, 2000)

The essential features of inquiry are those features of scientific work that are worthwhile for students to understand and use if they are to become scientifically literate citizens.

Despite these reform efforts, American students continue to be outperformed on international measures of science education. The results of the 2007 Trends in International Mathematics and Science Study (TIMSS) indicate that U.S. eighth-graders' scored lower than 9 of the 47 educational systems that participated in the study. Furthermore, the results of the 2009 Program for International Student Assessment (PISA) show that the average score 15-year-olds in the United States were lower than 18 of the 65 participating countries and other education systems (Fleischman, 2010). Several contributing factors have been identified including the continued use of a traditional didactic approach in science classrooms, the persistent use of TSM as the only representation of science offered to students, and the focus on preparation for standardized tests rather than deeper knowledge of the practices of scientists and the NOS.

The didactic approach, still common in American science classrooms, typically begins with a lecture or presentation of some chunk of science content that includes sets of more or less related facts and theories that are presented as pieces of knowledge that scientists' have established as truths. The teacher follows the sequence of the textbook closely, presenting the content listed as what "students are required to know" by the state standards on which, in many cases, their students will be assessed. The content, often presented as facts rather than tentative ideas, are further illustrated and discussed through the completion of a structured laboratory activity that follows the lecture. The laboratory activity engages the students in a set of procedures to identify the facts presented during

lecture. In other words, if the students follow the cookbook style directions provided by the laboratory handout, then the data should align with what was presented during lecture thus affirming the truth of the teacher's presentation. A lab report is typically assigned and requires students to identify each step of the scientific method and relate it to the laboratory activity that was performed. Summative assessment of student learning is accomplished by grading the lab report and administering a paper and pencil test that uses a variety of multiple-choice, short answer, and essay questions that require students to reiterate the content presented to them. Despite the large body of evidence from science education research that clearly identifies the shortcomings of the often didactic, "scientific method" approach, strategies closely aligned with TSM, such as those described above, continue to be used extensively in high school science classrooms (Windschitl, 2004).

Inquiry, the pedagogical alternative to didactic forms of instruction proposed by the NSES, has met many challenges to becoming the dominant instructional method in science classrooms. Challenges faced by teachers when attempting to implement an inquiry strategy include the teacher's beliefs about the NOS, the considerable time needed for planning successful inquiry lessons, and changing the power dynamics of the classroom from one in which the teacher controls the learning to one in which the students have increased control over the learning process (Lotter, Harwood, & Bonner, 2007; Roehrig & Luft, 2004; Wallace & Kang, 2004). Further exacerbating the problem, there are, within the inquiry movement, many different ways of implementing inquiry (discovery learning, project based learning, the case study approach, and model based inquiry) each with its own unique challenges. This variety, while seen as testament to the



highly applicable nature of inquiry by those familiar with inquiry, can be interpreted by novice teachers as a confusing set of strategies that may or may not be doable in the classroom (Anderson, 2007).

In response to the current state of science education in the United States, the National Research Council (NRC) and American association for the Advancement of Science (AAAS) developed a new framework for science education, A Framework for K-12 Science Standards: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2012). The Framework was developed using research-based evidence on how students learn, input from scientists and science educators, and the insights gained from past reform movements. The new framework did not propose to be the new standards but a basis on which new standards would be developed that reflects new understandings in the fields of student learning and science teaching.

There are several important differences between the NSES and the new Framework that will have an impact on the secondary science classroom as well as the field of science education research. The new framework focuses on depth of understanding rather than breadth of content knowledge, learning progressions across years of education and disciplines of science, and the integration of scientific practices with science content in meaningful and authentic ways.

### **Depth not Breadth**

The new framework and the resulting Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) are intended to move teachers and students away from these long lists of disconnected facts and towards a more integrated approach to learning science that reflects the success of inquiry approaches to teaching. Rather than distilling

science down to a series of unrelated facts, the new framework and standards attempt to lay the ground work for this effort by providing three key dimensions made up of 8 scientific practices, 7 cross cutting concepts, and 4 domains of science. The approach of the framework and standards is one that emphasizes the integration of the 8 practices into the students endeavor to learn the content. The 7 cross cutting concepts provide links between the 4 domains of science so that teachers and students can connect the ideas from the 4 domains into a coherent and scientific view of the world (NRC, 2011b).

Research has identified the importance of depth of teacher content knowledge when implementing reform strategies (Carlsen, 1992). In response to the changes in the expectations of classroom instruction called for by the NGSS, teachers will not only need to have deeper, more connected understanding of their own content knowledge but also need to recognize how the practices that embody the work of scientists should now be considered part of the content being taught to students. As a result, teacher educators will need to be able to provide professional development that deepens teacher content knowledge in one of the areas that will be outlined by the new standards while also providing new strategies for the delivery of this content that embodies the new framework's call for the integration of the core practices of science. This represents a unique and nascent challenge in light of most science teacher educators' background in discrete sciences, separated for the most part from other disciplines and integrated only when directly needed (Lederman & Lederman, 2013).

### **Learning Progressions**

The new framework is built on the premise that learning is a developmental progression. In order to develop a deep understanding of the scientific view of nature,

students need sustained opportunities to develop an appreciation of the interconnectedness of science over periods of years rather than weeks or months. This understanding has given rise to the development of learning progressions. Learning progressions provide a map of how students learn a particular concept. These maps identify the sequence of experiences and activities that lead to understanding of a targeted concept and the progressions are based on evidence based studies of how students learn rather than anecdotal or “best practice” ideas (Corcoran, Mosher, & Rogat, 2009). One unique character of learning progressions is their ability to be falsified. The development of a learning progression begins with a review of the relevant literature on how students learn a particular topic thus they are empirically grounded. As such, the next step for a learning progression is for it to be tested in real classrooms to ensure its accuracy. In this regard, learning progressions differ from traditional approaches to curriculum alignment. Quite often the authority of the developer and government agencies legitimate the scope and sequence documents used for establishing curricular decisions. Learning progressions are empirically based and if found to be ineffective can be modified or discarded. This quality provides for an iterative process through which research can inform, change, and improve the learning progression over time(Corcoran, et al., 2009). Teachers will need to become familiar with the view of student learning as a progression and be provided with opportunities to develop and use learning progressions in their classrooms.

### **Integration of Scientific Practices: Scientific Modeling in Particular**

The new framework seeks to acknowledge the connection between scientific knowledge and scientific practice through promoting student engagement in learning the scientific knowledge through engagement in scientific practices. If a student is to

understand the interconnectedness of the knowledge of science then they need to understand the processes by which that knowledge is generated. Scientists use a variety of practices in order to generate new knowledge. The new framework, on which the NGSS are based, has chosen 7 practices that are evident in most areas of science.

One of the most prominent practices in the new Framework and resulting NGSS is the practice of Scientific Modeling. Scientific Modeling is listed as a core disciplinary practice as well as a cross cutting concept, a distinction which no other topic has within the new standards. This unique position sheds light on the paramount importance of models and modeling in science education, a realization that until only recently has gone unaddressed in science classrooms (Justi & Gilbert, 2002c; Khan, 2011; Van Driel & Verloop, 1999a). Scientific modeling has also been described as a “keystone practice” and as such, participation in scientific modeling can serve as a link to other scientific practices (Mayer, Damelin, & Krajcik, 2013).

Scientific modeling provides an authentic scientific experience, an opportunity to engage in the learning of science content in a similar way to its initial discovery, and a method of inquiry that can be applied to other areas of life and the decision-making processes therein. Its prominence in the new framework supports this assertion and positions it as a key strategy for both student and teacher learning.

### **Inquiry Learning and the Connection to Scientific Modeling**

The new framework and standards have attempted to address the challenges met by Inquiry teaching by framing science as a set of intellectual and disciplinary practices in which students can engage, just as scientists engage in them when doing science. As such, learning the content of science through these practices provides an authentic,

scientific, and connected view of the discipline as a way of knowing rather than an isolated list of facts to be memorized. Understanding science as a way of knowing requires students to possess a basic understanding of the Nature of Science.

Although the debate over definitions and the meaning of the NOS continues among philosophers, educators, and historians, the characteristics of scientific knowledge that are agreed on provide a sufficient framework for K-12 educators on which classroom instruction can be based (Bell & Lederman, 2007). These characteristics are that scientific knowledge is tentative, empirically based, subjective, creative, and socially and culturally embedded. In order for teachers to engage students in understanding NOS, it becomes especially important for teachers to move from implicitly teaching the processes of science (observing, hypothesizing, predicting, experimenting, measuring, analyzing, inferring, communicating, etc.) as a linear process to explicitly teaching the non-linear, iterative, process of science.

One possible way to unite both the Nature of Science and the processes of science is by defining science as a process of constructing predictive conceptual models (Gilbert, 1991). This definition unifies the majority of scientific fields in a manner that is not possible by TSM (Windschitl, et al., 2008). The process of scientific modeling is an iterative one in that when an initial model is generated and its predictions tested, new information can result in a changed model. This new model's predictions are then tested and new information may result in a further change to the model. Thus, the tentative nature of scientific models and the iterative process of scientific modeling serve as a uniquely accurate example of the tentative Nature of Science and an especially effective strategy for explicitly teaching the Nature of Science and the processes of science. This

perspective is supported by the prominent role of models and modeling in both the practices and the cross cutting concepts, two of the three dimensions of the new Framework and subsequent NGSS (NGSS Lead States, 2013).

Model-Based Teaching (MBT) is an approach to teaching science that closely resembles the process by which many scientists learn about their specific field of study and as such, when implemented successfully, incorporates all of the essential features of inquiry as listed above. MBT is the set of learning activities, resources, and instructional approaches that facilitate mental model building in individuals or groups of learners (Gobert & Buckley, 2000). MBT is based on an understanding that science is a process of building, testing, and modifying scientific models (Gilbert, 2011). As such, it stands to reason that if students are expected to achieve the three primary goals of science education (learning the content of science, the history of science, and how to do science ((Hodson, 1992)) they should come to know the major historical models in science, appreciate the role of models and modeling in the process of science, and be engaged in the process of creating, testing, and communicating their own models (Henze, Van Driel, & Verloop, 2007; Justi & Gilbert, 2002a). Several strategies that facilitate the use of a model-based approach to inquiry learning have been described in the literature (Clement & rea-Ramirez, 2008; Hestenes, 1996; Passmore, Stewart, & Cartier, 2009; Schwarz & White, 2005; Windschitl, Thomson, et al., 2008). All of these strategies explicitly identify the importance of teachers being knowledgeable about scientific models and the process of modeling. Many other studies imply several other skills (e.g., leading student-to-student classroom discourse, explicitly illustrating the Nature of Science (NOS)) that are necessary for teachers to successfully implement a model-based instructional strategy

(Danusso, Testa, & Vicentini, 2010; Henze, et al., 2007; Hestenes, 1996; Van Der Valk, Van Driel, & De Vos, 2007; Xiang, Hvidsten, Dowd, & Beauchamp, 2010). Although challenges have been identified that range from personal to systemic in nature (Passmore, Xiang, Hvidsten, Dowd, & Beauchamp, 2010), the majority of the literature on using a model-based approach to teaching science alludes to these characteristics that good “modeling” teachers possess but does not explicate the magnitude of the effects these characteristics have on the implementation of MBT in the classroom. More specifically, few sources have been found that directly articulate the impact of skills such as facilitating modeling discourse through questioning, understanding of the Nature of Science, and knowledge of scientific models and scientific modeling on teachers implementation of MBT.

This study sought to understand the extent to which teachers’ understanding of the Nature of Science, ability to use questioning to facilitate modeling discourse, and knowledge of models and modeling impact their implementation of MBT in their classrooms. If the factors described above are truly important factors in the progression of teachers becoming effective modeling teachers, professional development opportunities should provide specific training that improves these three facets of model based inquiry implementation. By identifying new insights through the study of 15 middle and secondary science teachers before, during, and after a summer professional development institute focused on Model Based Teaching, I have generated a performance progression for teachers implementing MBT. The performance progress lends new insights into the processes teachers go through as they begin to implement MBT by articulating patterns teachers may follow when attempting to implement a new pedagogical practice in their

classrooms. The findings of this study will inform teacher educators' future design of effective professional development.

### **Personal Interest**

This topic became of great interest to me as I spent eight years teaching biology and chemistry in a program for highly gifted students. The traditional didactic approach to teaching was simply ineffective at engaging gifted students to think deeper and explore the content to a degree that was commensurate with their ability. I began searching for alternative methods of instruction and this led me to complete a Master's degree in secondary science education.

Through that process I learned about inquiry learning, conceptual change theory, and utilizing a constructivist approach to teaching. While I was learning about these various approaches I began to look for a pedagogical strategy that incorporated all of these theories and yet was coherently engaging. In other words, rather than implementing one style after another, which led to a discontinuous framework of teaching, I wanted to find one framework in which all of the "best practices" could be implemented.

My mentor at the time was a professor who had published several articles about using models to engage students in thinking more deeply about the content they were learning. I decided to create my own modeling lesson, which we later published in a peer-reviewed journal. The process of generating an idea, testing it in my own classroom, and subsequently publishing what I learned in a peer reviewed journal instilled in me the drive to further engage in the science education research process. The decision to continue my studies required choosing an area of science education that I was curious about beyond just a passing interest. Modeling Instruction, Model-Based Inquiry, and



Model-Based Learning, collectively fit that description. These processes engage students in an authentic scientific process of which multiple real world examples can be provided. Yet as I learned more about these methods, I found it increasingly difficult to implement the strategies in my own classroom. I wondered if there was research about the challenges of implementing model-based teaching in the secondary science classroom. The literature does contain information about the challenges of inquiry in general as well as the challenges for elementary and middle schoolteachers implementing model-based teaching. However I found relatively little mention of the specific challenges of implementing model-based teaching in the secondary classroom.

### **Research Questions**

Few studies have focused on exactly how and to what magnitude a science teacher's knowledge of the Nature of Science, the use of questioning to facilitate modeling discourse, and knowledge of scientific models and modeling affect their implementation of Model-Based Teaching. Thus, articulating the relationship these variables have with the implementation of MBT and gaining a deeper understanding of how these factors impact the implementation of MBT was the focus of this research. This study focused on the following three research questions:

1. In what ways does teachers' understanding of the Nature of Science (NOS) impact their ability to implement Model-Based Teaching?
2. In what ways does teachers' use of questioning to facilitate modeling discourse impact their ability to implement Model-Based Teaching?
3. In what ways do teachers' knowledge of scientific models and scientific modeling impact their ability to implement Model-Based Teaching?

The first part of this study focuses on the 15 participating teachers' understanding of the Nature of Science, their skills in using questioning to facilitate modeling discourse, and their knowledge of scientific models and modeling. Quantitative measures of these three factors for 15 teachers were compared to their level of implementation of MBT strategies in their classrooms. The second part of this study involved a multiple case study of three of the participating teachers, purposefully selected as unique cases of teacher progress towards effective implementation of MBT. The second part of the study focused on identifying how the factors in part one of this study impacted the teachers' implementation of MBT in their classrooms. Through a combination of quantitative and qualitative data analysis, this study will shed new light on how teachers learn to implement MBT and provide key insights into the design of effective professional development focused on MBT strategies through the articulation of a performance progression for Model-Based Teaching.

## CHAPTER 2

### LITERATURE REVIEW

This chapter will provide a discussion of the literature regarding the use of Scientific Models and the process of Modeling in both science and in science education. Also included is a review of the relevant literature on the Nature of Science (NOS) and on classroom questioning as they pertain to the implementation of Model Based Teaching (MBT). This chapter will then conclude with a review of the literature on effective professional development for secondary science teachers and how it may be used to develop teachers' content knowledge, pedagogical content knowledge, and metamodeling knowledge.

#### **Scientific Models and Teaching Models**

The process of developing, applying, and revising scientific models has been described as a fundamental part of every scientific discipline (Passmore, et al., 2009; Windschitl, Thomson, et al., 2008). Models are an integral part of both the processes and the purpose of science. Gilbert (1991) describes science as a process of constructing predictive conceptual models and Harrison and Treagust (2000, p. 1011.) state that "Modeling is the essence of thinking and working scientifically". Model building, when viewed in this manner, serves to unify the various fields of science that utilize a multitude of methodologies (Gilbert, 1991). The purpose of this model building, as is the purpose of science in general, is to produce models that represent consistent, predictive

relationships. Thus Scientific Models are generated, applied, tested, and revised extensively by scientists (Van Driel & Verloop, 2002b) and as such, models and the process of modeling should play a central role in science education (Justi & Gilbert, 2002b).

Although models have been defined in a variety of ways, the word typically refers to the internal Mental Model or the external Expressed Model (Gobert & Buckley, 2000). Clement and Rea-Ramirez (2008) describe the Mental Model as being a personal representation built on personal experiences or knowledge of the phenomena being modeled. The Mental Model is an abstraction of a particular system or phenomenon and as such are not one-to-one representations of a physical reality (Halloun, 2007). Due to the personal nature of Mental Models, they are often extremely dynamic and difficult to assess and as such, tend to possess misconceptions and errors and thus are the focus of instruction (Harrison & Treagust, 2000). Since others cannot directly evaluate another person's Mental Models, the construction of Expressed Models is necessary for the evaluation and communication of the Mental Model. Gilbert and Boulter (1998) describe the Expressed Model as a version of the Mental Model that the possessor of the Mental Model creates either through drawings, verbal discourse, or other forms of model building.

The Expressed Model of a scientist, once it has gained wide peer acceptance through peer review and testing, may become a Consensus Model. Consensus Models that are in current use as predictive and explanatory tools by scientists are referred to as Scientific Models and are defined by many science education researchers in a variety of ways. Boulter and Buckley (2000) define Scientific Models as representations of an idea,

an object, or process in which a target is matched with an analog. Hestenes (1996) defines a Scientific Model as a unit of structured knowledge used to represent observable patterns in physical phenomena. Cartier, Rudolph, and Stewart (2001) define a Scientific Model as a set of ideas that describe a natural process. Scientific models, once discarded for better models, can be considered Historical Models. Well known historical models include Rutherford's solar system model of atomic structure.

The process of generating an Expressed Model from a Mental Model is a way of making thinking visible. When students are engaged in a drawing task to make their Mental Models explicit, the drawing can be used for collaborative discourse as well as an artifact that can be revised based on new ideas and learning activities (Gobert & Pallant, 2004). Gobert and Pallant (2004) showed how students with more sophisticated understandings of models were better able to understand content than students with more naïve understandings of models.

Although the definitions of a model vary, descriptions of the process of generating models share much in common. A model is generated based on an observation of a real world phenomenon, tested for its explanatory and predictive ability, modified by new empirical evidence so that it can better represent observations of the real world (Windschitl, Thomson, et al., 2008), and then presented as part of an evidence based argument to other scientists for peer review.

Scientists generate Scientific Models and use them for a variety of reasons including organizing their ideas, testing predictions, generating new ideas or predictions, and communicating their research findings and conclusions to other scientists (Van Der Valk, et al., 2007). Scientific Models will differ in regards to content and function

according to the specific field of science in which they are generated. Nevertheless, scientists generally agree that common characteristics of all Scientific Models include a relationship to a target while being different from the target and an ability to predict or explain a natural phenomenon (Van Der Valk, et al., 2007).

Scientific models can be significantly different from Teaching Models used in science classrooms. Teaching Models can be generally categorized as analogical models (Harrison & Treagust, 2000). These models are often constructed for teachers or by teachers to be used for conveying knowledge of a curricular concept. Scale models, like model airplanes or models of plants or animals, are used as visual tools for describing some object. They are analogical in that they are often smaller or larger than the real thing and made of different materials. Chemical formulas or other symbolic models can be used to simplify the process of explaining complex chemical processes. Mathematical models such as equations and graphs can represent physical phenomena that are not objects but processes, for example Boyle's Law or Newton's Laws of Motion. Maps, diagrams, or tables can represent patterns or relationships and can help students visualize complex processes. Concept process models such as food webs or energy pyramids can be effective explanations for otherwise unobservable phenomena such as island formation or erosion. Simulations, either physical or computer based, can help students to understand dangerous or otherwise unobservable processes. All of these models are analogical models because there are simplified or exaggerated representations of physical or theoretical processes and as a result, their ability to explain or depict a phenomenon eventually breaks down (Harrison & Treagust, 2000). In other words, the target of the model is always more complex than the model. In order to compensate for this, multiple

models can be employed for the same phenomenon but focus on different constituent parts of the phenomenon (Crawford & Cullin, 2004). For example, a globe is a scale model of the Earth but a simulation of tectonic movement might lead to the use of a concept process model describing the movement of the Earth's mantle.

All of these types of analogical models are used to teach students about the Scientific Model. The Scientific Model, also referred to as an Expert model or Target model (Clement & Rea-Ramirez, 2008), is one that has been tested and has come to be generally accepted by experts. The Teaching Model is a less complex version of the Scientific Model in that it is constructed with the purpose of teaching parts of the Scientific Model. Since its purpose is to explain the Scientific Model it is often simplified to a level that is associated with the intended audience.

Van der Valk, Van Driel, and De Vos (2007) identify seven salient features of scientific models as they pertain to science education. They include (a) the distinction that a model is always related to a target and is designed for a specific purpose and as such, it is always possible to distinguish between the model and the target; (b) a model serves as a research tool in that models are used to obtain information that cannot be easily observed or obtained supporting the purpose of a model as mostly to predict or to explain phenomena; (c) a model bears some analogy to the target and these analogies enable the researcher to derive hypotheses or make predictions that can be tested while studying the target; (d) models differ in certain respects from the target and these differences make the model more accessible than the target; (e) models are always developed as a compromise between the demands of being a good analogy for and being different from the target; (f) models do not interact directly with the target and as a result

there is an element of creativity in their design; (g) several consensus models may co-exist in order to represent a target; (h) models evolve through an iterative process.

The prominence of model building and use in science is justification for the inclusion of models and modeling in science education. When students are engaged in learning about the process of model construction in an authentic way, they are taking large steps towards understanding the “business” of science and well on their way to science literacy. The multiple levels of accessibility for engaging in modeling can provide avenues for the realization of “science literacy for all” called for by modern reform documents such as the Next Generation Science Standards (NGSS)(NGSS Lead States, 2013).

### **Teacher and Student Knowledge of Scientific and Teaching Models**

Most students recognize models as copies of phenomena and have a simplistic conception of models in general (Grosslight, Unger, Jay, & Smith, 1991; Schwarz & White, 2005). Treagust, Chittleborough, and Mamiala (2004) affirm in their study of secondary students’ that although students have a sound understanding of the descriptive nature of teaching models, their understanding of the predictive nature of those models is limited. In a study of 19 high school students where the focus of instruction was on model assessment, Cartier (2000) noted that all students were able to assess models based on empirical fit but not on conceptual congruence with other models or within the model itself. Cartier proposed that this was due to the students’ lack of understanding the conceptual nature of models beyond their physical properties.

These findings, that indicate students’ naïve understanding of scientific models and modeling, are not surprising in light of the large body of literature suggesting that



both experienced and prospective science teachers' knowledge of models and modeling is often limited, inadequate, and may include inconsistencies (Crawford & Cullin, 2004; Van Driel & Verloop, 1999b) that result in students seeing science as overly simplified and static. Furthermore, despite the importance of models and modeling in science and in stark contrast to the importance of models and modeling that scientists attribute to them in the course of scientific practices, researchers are now demonstrating that pre-service and in-service teachers do not fully address nor understand the importance of developing student understanding of the model-based definition of science (Justi & Gilbert, 2002b; Van Driel & Verloop, 1999a, 2002a).

In a study conducted by Van Driel & Verloop (1999), in-service science teachers shared the general definition of models as simplified or schematic representations of reality (Van Driel & Verloop, 1999b) and emphasize the explanatory function of models while other important functions of models, such as using a model to make predictions, were rarely mentioned. However, they also found that teachers' content knowledge of models and modeling was both limited and diverse. Among the teachers who held more informed views of models, there was evidence that these teachers held an integrated positivist and social constructivist epistemological orientation in their practical knowledge. In other words, teachers with more informed views of models tended to temper a positivist epistemological stance with social constructivist ideas.

In a study focused on supporting prospective teachers' knowledge of models, Crawford and Cullin (2004) found that in spite of professional development focused on modeling, prospective teachers did not achieve full understanding of scientific modeling. Windschitl (2004) further elaborated on these findings, identifying how the most

common assumptions of pre-service teachers about what it means to “do science” amount to a “folk theory” of science largely attributable to the prominence of an atheoretical scientific method. Further research by Khan (2011), identified common practices of modeling that were missing from most teachers’ implementation of modeling in the classroom. These included the modification of models and the systematic cycling between evaluation and modification of models. It is, as a result, no surprise that students lack adequate knowledge of Scientific Models as well.

Grosslight, Unger, Jay, and Smith (1991) used a semi-structured interview to collect data about students’ general understanding of the term “model”. When used with students, the questions in that interview were supported by the use of physical examples of models (toy airplane, a diagram of the water cycle, etc.). The questions were then asked of experts in the field of science to establish comparison group for analysis. Their analysis led to the development of three general levels of understanding of scientific models. However, only the third level, the expert level, was given a robust descriptive account of understanding. In order to assign number scores to each individual student, the Grosslight et al., (1991) study developed six dimensions of one’s understanding of models. The development of these dimensions allowed the researchers to assign students a score of 1, 2, or 3 for each dimension. These scores were averaged and used to assign a general level of knowledge of scientific models to each student.

Attempting to illuminate experienced teachers’ knowledge of models and modeling, Van Driel and Verloop (1999) designed an open response questionnaire based on the Grosslight et al., (1991) interview which focused on four themes within the knowledge structure of experience teachers; the types of models, the role of models in

science, characteristics of scientific models, and role of modeling in science. They followed the open response questionnaire with a Likert type questionnaire. They found that experienced teachers' knowledge of models and modeling was limited. Teachers with a more developed understanding of models and modeling tended to have a more social constructivist view of teaching and learning than those with a less developed understanding of models who held a more positivist view of science. This study asserted that while teachers' held similar definitions of a scientific model, they held very different views of models and modeling.

Justi and Gilbert (2002) developed a survey for experienced science teachers in Brazil aimed at illuminating teachers' views of the nature of models, the nature of modeling and implications for its use in science education, and about the use of models and modeling in teaching and learning science. Their analysis resulted in general themes, ideas and understandings of the participants. Their analysis did not develop rich descriptions of each participant; rather they developed general categories of the things teachers understood as relevant or important in relation to models and modeling. For example, they found that teachers, in general, thought that either the integrity of scientific models was too important to be modified enough for use in the classroom or that scientific models could be simplified enough to be considered useful teaching models. While this finding provides some insight into teachers generally, it does not provide insight into how one of these beliefs might impact a teacher's ability to implement model based teaching.

Crawford and Cullen (2004) built on this growing body of literature by developing a survey used with prospective science teachers. This survey was given to

prospective teachers and aimed at identifying the developing understanding of prospective teachers understanding of modeling in science. The survey consisted of 8 open ended questions, 6 aimed at knowledge of models and 2 additional questions designed to elicit their views about teaching about scientific models. The authors followed up the survey with a semi-structured interview to further explore the responses. Where the Grosslight et al. (1991) survey led to general descriptions of levels of model knowledge, Crawford and Cullen's survey with the follow up interview, provided a richer data set about teachers' conceptions of models and ideas about teaching about and with scientific models. They found that prospective teachers became more familiar with the language of modeling and were able to think critically about models and modeling, but did not achieve full understand of scientific modeling. These findings implied that simply experiencing scientific modeling and improving facility with the language of modeling may lead to teachers using models in their classroom more often but will not likely lead to teaching about models and modeling.

### **Multiple Strategies for Teaching through Modeling**

Similarly to the various ways Scientific Models are employed by scientists, science educators have developed a variety of frameworks for implementing instruction focused on the use of Scientific Models. In the following section, I will outline three of the most popular frameworks for implementing model-based instruction.

Model Based Inquiry (MBI) is an iterative and cyclic methodological approach to inquiry learning in the science classroom that involves the development, use, assessment, and revision of models (Passmore, et al., 2009) to explain patterns in collected data or real world phenomena. MBI typically begins with an activity that engages students in a

topic either through presenting a discrepant event or demonstration of a particular phenomenon. Students generating an initial model of what is happening and why it is happening follow this activity. This can be a diagrammatic representation, a physical model, or even a verbal model. The initial model is then used to formulate some testable questions and experiments or observations are completed to either support or refute the initial model. Based on what is learned, the model can then be refined, modified, or discarded depending on the findings. This revision process results in a new model that should better represent the phenomena. This refined and modified model can then be used to predict or explain other similar phenomena. Once this cycle is complete students then generate an evidence-based argument describing the phenomena being studied and use their evidence-based model in support of their argument. Different methods of enacting each of these steps in the process can be used but the overall guiding steps are cyclic and iterative in nature.

Modeling Instruction (MI) is a similar but slightly different approach to teaching through modeling. MI is organized around two general classes of modeling activities: model development and model deployment. The model development stage includes a descriptive phase in which students are guided by the teacher in a process of describing the fundamental measurable parameters of a phenomena that might exhibit a cause and effect relationship. The students then turn to the formulation phase in which they develop a functional relationship between some or all of the identified fundamental parameters through the design and carrying out of experiments. The data collected is then used to generate a mathematic model based on evidence collected during experimentation. Teams

of students carry out experiments then analyze and present their data to the rest of the class.

During the model deployment stage, students apply their models to new situations or related problems to solve. The solutions are then presented to the rest of the class through an activity called white boarding. White boarding is an activity that requires students to generate a poster on a white board that includes a diagram of their model, the mathematical relationship, and the solution to the problem.

Model Based Teaching (MBT) begins with aligning with student prior knowledge, supports students authentic inquiry skills, develops understanding of the process and nature of science, and as a result, leads to significant improvements in scientific literacy (Gobert & Pallant, 2004). Gobert and Buckley (2000) succinctly define MBT as any instructional strategy that brings together information resources, learning activities, and instructional activities that intend to facilitate mental model building both in individuals and among groups of learners.

Clement and Rea-Ramirez (2008) describe the process of Model Evolution as a student-teacher interaction process that begins with the identification of students' initial models and proceeds through an iterative process of developing intermediate models until reaching the target model of the lesson.

Implementing any of these strategies effectively often requires a great deal of practice and can take a considerable amount of effort and time on the part of the teacher. Teachers who demonstrate skilled use of model-based strategies in the classroom possess several common characteristics associated with skillful implementation. These include management of classroom discourse through the use of thoughtful questioning that

engages students in productive discussions leading to students being able to generate evidence based arguments (Hestenes, 1996; Passmore, et al., 2010). Teachers who are successful at implementing model based strategies also need adequate understanding of the nature of models and the process of modeling with respect to an overarching understanding of the Nature of Science and how the processes of science, model building in particular, generate the body of scientific knowledge (Danusso, et al., 2010; Henze, et al., 2007). While the focus of this study is on how the factors above impact teachers' implementation of MBT, other factors may impact a teacher's implementation of MBT including contextual or cultural factors such as school resources, importance of high stakes testing, or student socioeconomic status (SES).

### **Scientific Models and the Nature of Science**

Abd-El-Khalick and Lederman (2000) found that in addition to teachers' lack of knowledge of models and modeling, they also lack an adequate understanding of the Nature of Science (NOS) and its processes of knowledge building in science. Although the debate over definitions and the meaning of the NOS continues among philosophers, educators, and historians, the characteristics of scientific knowledge that are agreed on provide a sufficient framework for k-12 educators on which classroom instruction can be based (Bell & Lederman, 2007). These characteristics are that scientific knowledge is

- tentative
- empirically based
- subjective
- creative
- socially and culturally embedded

The tentative nature of science arises from the understanding that our current state of knowledge is at best flawed and new information can resolve inconsistencies. In other words, as new information arises, the new information is weighed against the current understanding and may in fact change the accepted understanding thus rendering the current state of knowledge as temporary. Despite this tentative aspect of the NOS, most scientific knowledge is durable and it should be understood that certain theories in science have changed little for long periods of time. However, upon closer inspection, even theories as robust as that of biological evolution, have undergone slight modifications as new examples and new information becomes available (Abd-El-Khalick & Lederman, 2000).

All science is empirically based. In other words, any scientific argument must be supported by evidence. This evidence could be collected through experiments, direct observation, or even inference. Furthermore, the arguments put forth as scientific must be able to withstand a process of peer review, which will evaluate the empirical nature of the position being presented (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002).

The subjective nature of science arises from the understanding that science rarely begins with a random or isolated question and that most questions are rarely neutral. Scientists are motivated to make observations of the world around them and that world is viewed with a degree of bias that emanates from previous experiences, beliefs, and training. These experiences serve to guide a scientist's theoretical perspective and so any scientific idea that arises within such a perspective is inherently subjective (Bell & Lederman, 2007).



In order to generate a testable hypothesis or model, a scientist must actually think up or create a possible explanation for the phenomena in question. They may have to imagine a possible solution to a problem and then take steps to realize what was imagined. These are creative processes and as a result impart a certain level of required creativity in the process of science (Abd-El-Khalick & Lederman, 2000).

Science is a human endeavor and as such occurs within the larger context of human culture. Not only is science affected by the culture in which it is conducted but it also, in turn, affects the culture. It is with this understanding that science must be seen as a culturally embedded and social enterprise (Abd-El-Khalick & Lederman, 2000).

### **NOS and Inquiry**

The process of science includes those activities that relate to the collection and analysis of data through scientific inquiry. Scientific inquiry is not the Nature of Science; it is a process of science. NOS is best taught within the process of inquiry as a context for learning (Lederman, 1999). These inquiry experiences provide the necessary context on which thoughts about NOS can be applied. However, in order for teachers to develop their own deeper understanding of the NOS during professional development, direct and clear connections need to be made between the inquiry activities being used and the NOS (Akerson, Hanson, & Cullen, 2007).

Research has shown that teachers who have reasonably acceptable views of the NOS may not intentionally plan their instruction to teach that view of the NOS to students (Lederman, 1999). Years of teaching experience impact their efforts as well. Experienced teachers (>5 years) were more likely to include activities that teach the

tentative nature of science but less experienced teachers (<5 years) described challenges to using these activities.

### **The Argument for Models in the Classroom**

It is interesting to note that the qualities of scientific models described by Van der Valk, Van Driel, and De Vos (2007) more than loosely align with the generally accepted features of the Nature of Science that should be taught to students (Lederman, 1999) in order for students to be considered scientifically literate (NRC, 1996). Crawford and Cullen (2004) noted the direct relationship between the tentative nature of science and continual revision and evaluation of the modeling process. Taking this idea one step further, there are many relationships between multiple aspects of the NOS and the process of Scientific Modeling. The modeling process could serve as an especially effective method of achieving scientific literacy that emerges from a refined and well-developed understanding of the Nature of Science. Table 2.1 below identifies this alignment and how it correlates to the goal of science education as the production of scientifically literate students.

Table 2.1

*NOS-Modeling-Scientific Literacy*

	Nature of Science (Bell & Lederman, 2007)	Nature of Models	Scientific Literacy (NRC, 1996)
Tentative	Scientific knowledge changes with new evidence. (e.g., The Atomic Model)	Modeling is an iterative process that continues with new information.	A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it.
Empirical	Arguments must be supported by evidence in order to be considered scientific arguments.	In order for a model to be changed new empirically based evidence must be brought forward.	Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.
Subjective	The theoretical perspectives of scientists guide research and analysis of data.	Multiple models for one phenomenon can coexist simultaneously.	Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences.
Creative	Scientists often generate creative explanations for phenomenon.	Model generation is a creative process. (formation of an analogy for natural phenomenon)	It means that a person has the ability to describe, explain, and predict natural phenomena.
Socially and Culturally Embedded	Science is a human endeavor and as such scientists approach their work from cultural perspectives.	Particular models are generated and used to explain phenomena to specific audiences.	Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions.

In light of Table 2.1, one could argue that modeling is *the* appropriate method of science instruction that links the Nature of Science with the goal of scientific literacy called for by national reform documents. Furthermore, MBT is a pedagogical framework

that embodies the sociocultural and social constructivist perspectives. The iterative, socially dependent nature of the MBT process emulates very closely the community of practice of real scientists. Just as scientists generate knowledge through social interactions, students can generate their own “new” knowledge in similar ways. From a sociocultural perspective, learning involves the change from one sociocultural context to another by participating in shared activities (Lave & Wenger, 1991). If students participate in cooperative learning activities that are framed as activities in which real scientists engage, then they are more apt to see themselves as scientists and as such, becoming acculturated into the community of science (Coll, France, & Taylor, 2005).

### **The Importance of Questioning in Classroom Discourse and Model Based Teaching**

David Hestenes (1996) asserts that, “The most critical element in the successful implementation of the modeling method is the skill of the teacher in managing classroom discourse” (p. 19). When viewing teacher education and student learning through a sociocultural/ social constructivist lens it is important to recognize Lev Vygotsky’s (1978) perspective on development and learning. He asserts that higher mental functioning in the individual derives from social life. If we consider the construction of knowledge in the educational setting as a higher mental function then we may assert that learning is a social and constructive process developed within the social context of the classroom (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Duit & Treagust, 1998). Within the science classroom students and teachers may differ in the types of social language they use. When teachers and students engage in science talk in the classroom, it is a social interaction through which roles and positions relating to each other are established (Oliveira, 2009). So if learning science requires the student to internalize and

effectively use the social language of science (Vygotsky, 1987) then it is of paramount importance for teachers to effectively bridge the gap between scientific social language and the students' culturally influenced spontaneous and everyday language.

Thus learning is a social enterprise that is often developed through discourse. Discourse has been defined as language in use and is typically longer than a sentence. Discourse is also language that is related to social knowledge and identity as well as power (Kelly, 2007). An important point is that when students are asked to use science discourse in the classroom this can be very foreign to the types of social discourse they may be accustomed to outside of the classroom. In other words, scientific discourse can serve to empower students whose social status uses a similar form of discourse while alienating those students whose cultural discourse is very different from that of scientific discourse (Kelly, 2007). One skill a teacher needs to possess is the ability to generate an atmosphere that leads to productive discourse for all students rather than only those few who are already familiar with its subtleties.

Since language is the primary tool for social interaction then discourse plays a central role in the learning of science (Mortimer & Scott, 2000). Kelly (2007) points out three observations that support this understanding. First, that teaching and learning occurs through processes that are primarily facilitated by discourse. Second, that student access to science is gained through engaging in the social and symbolic practices of specialized communities within science. Third, the content of science is developed and communicated through the use of language. Thus, scientific discourse is central to understanding the epistemological base of science.

Although the importance of discourse in the secondary science classroom is well documented, much of this classroom discourse remains teacher-driven and didactic. Lemke (1990) described how classroom discourse was often controlled by the teacher, presented in a final refined way that hid the generative, iterative nature of science knowledge generation, and in turn, served to disengage students from the discourse rather than engaging them in an opportunity to “talk science”. Facilitating productive classroom discourse is difficult and requires a great deal of effort on the part of the teacher (Alozie, Moje, & Krajcik, 2010). The ineffective practices of teachers results in an unjustified authority of scientific knowledge and the authority of the teacher. Furthermore, ineffective classroom discourse practices serve to alienate students from science discourse while also providing a false understanding of the Nature of Science as authoritative.

A key teacher skill in managing effective classroom discourse is the use of questions (Harris, Phillips, & Penuel, 2011). Teachers use questions to ascertain what students know. A typical classroom-questioning episode involves a sequence in which a teacher initiates the discussion with a question. This is followed by a response from a student and then the teacher evaluates the response by commenting on its correctness. This sequence has been identified as the Initiate, Respond, Evaluate (IRE) strategy (Cazden, 1988) or Triadic Dialogue (Lemke, 1990). This form of teacher questioning does little to engage students in interactions that foster participation in scientifically productive discourse. Often teachers may take this one step further towards productive questioning but still remain inattentive to student ideas is through a process of funneling. Funneling is when a teacher uses a succession of questions to guide students to answering

one correct answer (Herbal-Eisenmann & Breyfogle, 2005). When teachers are able to enact productive classroom discourse that is open to ideas that arise, is attentive to student ideas and prior knowledge, and pursues productive ideas and questions, students are likely to deepen their understanding of both the content and process of science, and as such, the Nature of Science (Osborne, 2010). Minstrell and van Zee (2003) identified an alternative approach called the reflective toss. In this form of questioning, the teacher encourages student-student discussion through a careful framing and selection of questions in an effort to foster true dialogue, which leads to greater shifts in student understanding. This method of questioning shifts the authority from the teacher and that of science to the students as they generate their new understanding. The teacher serves as a guide, thoughtfully guiding that understanding towards the scientifically accepted viewpoint rather than authoritatively giving the ideas to the students. The difference lies in how the students arrive at the understanding with the perceived self-construction being the more effective strategy for long-term understanding. Additional questioning strategies such as “focusing” improve upon strategies such as IRE and funneling (Herbal-Eisenmann & Breyfogle, 2005).

A more robust preparatory practice for developing questions and preparing for student responses is situated within a framework for planning whole class discussions known as the Five Practices (Stein, Engle, Smith, & Hughes, 2008). One of these five practices for lesson planning is described as “Anticipating”. This practice involves the anticipation of likely student responses to cognitively demanding tasks, or in this case, questions. Anticipating begins by teachers actually answering the questions they plan to pose to the students and going beyond their own answer to consider all of the possible

ways students might answer the question. This preparatory activity affords a teacher with an opportunity to consider the level and timing of each question they ask and thus reduces the improvisational load on the teacher to think of a question on the spot.

Although the importance of questioning in the successful implementation of inquiry (Minstrell & van Zee, 2003). and more specifically, model-based inquiry (Hestenes, 1996) has been reasonably established, the body of research focused specifically on the professional development of teacher questioning is sparse (A. Oliveira, personal communication, November 18, 2011). Oliveira (2010) describes a one day session on teacher questioning presented in the third year of a multi-year professional development institute. The third and final summer institute was focused on model-based instruction with a primary emphasis on teacher questioning. Thus, a sustained PD experience focused on teacher questioning led to an increased awareness of the importance of teacher talk when establishing an inquiry classroom.

In one published study that focuses specifically on improving teacher questioning through professional development (Oliveira, 2010), the author identifies the effectiveness of providing an intensive discussion on types of questioning that lead to higher levels of student thinking. These include asking open-questions rather than closed questions and you-questions rather than pseudo-questions. Open questions have multiple acceptable answers while closed questions have only one possible answer. You-questions engage students in responding with their own thoughts rather than pseudo questions which ask students to guess what is in the head of the teacher. This extensive discussion was followed by an inquiry immersion session similarly to those previously described. The inquiry immersion was followed by an opportunity for teachers to reflect on the



facilitators questioning used during the inquiry session. Teachers then critiqued videos of their own instruction that were recorded in their classrooms prior to the professional development institute. Although this study was situated within the context of a larger professional development program focused on the use of models and modeling in inquiry based instruction, the findings suggest that these activities focused on teacher questioning improved the teachers' awareness of the impact their questioning had on the inquiry environment in their classrooms.

In another study, Viiri and Saari (2006) suggested that a review of an expert teacher's talk patterns followed by analysis and discussion of these expert patterns should be included in professional development. Explicit examples of the most appropriate form of dialogue and questioning can provide the novice teacher with concrete exemplars of practice to compare their own practice. (Viiri & Saari, 2006) Findings also indicate that during instruction about planning, lesson plans should include not only content objectives but also discourse objectives, making the planning of the types of talk that fit with particular learning objects explicit both in the planning and implementation of instruction (Viiri & Saari, 2006).

In an analysis of multiple professional development programs, Park Rogers et al. (2010) identified five particular orientations of professional development designers. One of these five orientations was called a "pedagogy driven" orientation wherein professional development is focused on a particular inquiry-based instructional strategy. One example of this type of orientation was the focus on teacher questioning. Although professional development focused on teacher questioning was identified in this study as

an example of a professional development orientation, little has been written about it in the science education literature.

### **Professional Development**

Professional development (PD) programs have been described as systematic efforts to bring about change in teachers' classroom practice that lead to improved learning outcomes of students (Guskey, 2002). In the process of improving the state of science education, high quality professional development serves a central role in the movement towards effective changes in classroom practice, student achievement, and teacher beliefs and attitudes about science and teaching (Guskey, 1986). Despite the long history of ineffective and disorganized professional development in American schools, research into effective professional development has yielded insights that guide the implementation of highly effective professional development.

The National Science Education Standards (NSES) (1996) describe four themes that should innervate professional development programs for science educators. These themes are described as the Standards for Professional Development for Teachers of Science and include: Learning Science through Inquiry, Learning to Teach Science through Inquiry, Becoming Lifelong "Inquirers", and Building Professional Development Programs for Inquiry-Based Learning and Teaching (NRC, 2000).

More recently, the particular focus of PD programs for science teachers has varied but several fundamental practices have been shown to lead to successful outcomes. Several are particularly well suited to the professional development of teachers focused on Model-Based Teaching. These include providing sustained professional development (Freeman, Marx, & Cimellaro, 2004; Loucks-Horsley, Hewson, Love, & Stiles, 2003;

Williams, 1994), opportunities to deepen content knowledge (Carlsen, 1993) , opportunities for reflection and community building (Schulman, 1987; Viiri & Saari, 2006), engagement in inquiry immersion (Loucks-Horsley, et al., 2003; Rushton, Lotter, & Singer, 2011),time dedicated to curriculum (Hvidsten, Dowd, Xiang, & Passmore, 2010), and opportunities to participate in practice teaching (Rushton, et al., 2011).

A hallmark of the modern reform of teacher professional development is the movement from “one-shot” workshops offered by school districts to multi-week summer institutes provided by teacher educators from universities and colleges that often include Saturday workshops which extend the PD into the school year (Freeman, et al., 2004). Summer Institutes allow teachers to work with University level educators and can provide the quality and depth called for by national standards. The literature suggests that a successful institute should include hands-on experiences, outside scientific expertise, master (expert) teachers, practical applications and follow-up contact (Loucks-Horsley, et al., 2003). This sustained professional development rather than short one time PD has led to greater teacher efficacy with regard to the focus of the professional development.

Teacher content knowledge has an important impact on many characteristics of classroom practice. More specifically, a lack of teacher content knowledge in a particular area impedes on the freedom teachers will give students during dialogue. The more content knowledge the teacher has about the topic being discussed, the more comfortable they are with allowing the dialogue to proceed. Quite often, when a teacher lacks significant background knowledge, the dialogue is purposefully limited and thus not as engaging for the learner (Carlsen, 1993).

Another best practice in teacher professional development is the opportunity to reflect on the focus of the PD (Schulman, 1987). Reflection can be supported in a variety of ways including daily journaling, group discussions, online discussion boards, and many others. In an exploratory case study investigating teacher talk patterns, Viiri and Saari (2006) suggested that reflection on teacher talk patterns should be included in a prolonged professional development and not only on a small number of occasions. The reflection component was especially important because teachers described the difficulty in changing the talk patterns that they saw in the videos of themselves teaching thus providing an avenue for bringing to light the progress of the change in teacher dialogue.

The benefit of this opportunity for reflection is further magnified when it is done within a community of learners. This reflective practice within a community of learners exemplifies the view of science learning as a socio-cultural constructivist activity (Vygotsky, 1978). As such, the dialogue which teachers engage in is not only socially satisfying but is actually a part of the learning process. As teachers begin to demonstrate an increased awareness of the impact of discourse on learning, the opportunity to share these new understandings with each other from within a community of learners serves to reinforce the learning (Lave & Wenger, 1991).

When engaged in PD that focuses on moving teachers towards a more inquiry based classroom, it is recommended that teachers be immersed in inquiry learning (Loucks-Horsley, et al., 2003). During inquiry immersion, teachers typically take on the role of student and learn new science content through inquiry. In some types of inquiry immersion, role playing student thinking is encouraged. This affords teachers an opportunity to learn through inquiry and see the method from a student perspective.

During these inquiry immersion sessions, teachers can also see how an “expert” instructor implements inquiry (Rushton, et al., 2011).

An additional practice that has led to successful changes in teacher classroom practices is the opportunity to engage in curriculum development that incorporates the newly learned strategies (Hvidsten, et al., 2010). This opportunity to engage in curriculum development is further supported when the initial opportunity to practice the lesson occurs at the PD institute (Rushton, et al., 2011). These microteaching opportunities can be done with students during the summer institute or with fellow teacher participants engaged in the role-play of student thinking.

### **Professional Development for Scientific Modeling and the Nature of Science**

Professional development focused on model based instruction should engage teachers directly in the process of modeling by going through the four basic elements of the practice; constructing, using, evaluating, and revising models. Engaging in this process directly promotes the development of metamodeling knowledge in teachers (Schwarz & White, 2005). Metamodeling knowledge is a teacher’s or student’s understanding of scientific models and of the process of modeling and is described as a form of Nature of Science understanding (Schwarz & White, 2005). Metamodeling knowledge includes the understanding about how models are used, why they are used, and their strengths and limitations. Thus, metamodeling knowledge can be associated with a teacher’s appreciation for the dynamic nature of scientific knowledge and its acquisition. Engaging teachers in the modeling process also helps them to understanding the sense-making and communicative purposes of models, the model’s ability to explain

a phenomenon, and the model's predictive ability when applied to new phenomena (Kenyon, Davis, & Hug, 2011).

Research on professional development focused on model-based instruction also emphasizes scaffolding as a necessary support for teachers engaged in learning about model based strategies of instruction (Crawford & Cullin, 2004; Justi & Gilbert, 2002b; Passmore, et al., 2010; Schwarz & Gwekwerere, 2007; Windschitl, Thompson, & Braaten, 2008; Windschitl et al., 2011). Given that modeling is not an easy practice to facilitate in the classroom, scaffolding can provide the necessary support structure to help teachers in the process. The scaffolding can range from giving teachers the curricular materials for classroom use that require little or no modifications to guiding teachers in their development of new units of instruction that include lessons that engage students in model based learning.

In their work with prospective and early career science teachers, Thompson, Braaten, and Windschitl (2009) developed a learning progression that describes how early-career teachers plan, enact, and assess various components of model-based instruction. The learning progression consists of eleven different dimensions of reform teaching that support Model-Based instruction. The authors found that providing teachers with a condensed version of the progression fostered teacher progress in their implementation of model-based instruction by providing the teachers with a vision of where they currently were located and where they could possibly go next with regard to their practice.

Professional development focused on the Nature of Science should be differentiated for experienced and less experienced teachers (Lederman, 1999).

Experienced teachers, that may or may not have appropriate views of the nature of science, are different from less experienced teachers in that they have learned through their experience how to manage a classroom sufficiently to explore what is perceived as a more “abstract” idea in the Nature of Science. Less experienced teachers in Lederman’s (1999) study were more concerned with “managing” the classroom well and described that trying to teach the nature of science was too difficult. These differences in opinion across experience indicate that experienced teachers should be provided strategies and approaches to making the teaching of the Nature of Science explicit while less experienced teachers must be first taught ways of managing the classroom so as to be conducive to learning about the Nature of Science (Lederman, 1999). Akerson, Hanson, and Cullen (2007) noted that in order to be effective, professional development focused on the NOS should be explicit and reflective. Providing explicit-reflective instruction on the NOS within an authentic inquiry context has been found to be effective in improving secondary teachers’ views of the NOS (Schwartz, Lederman, & Crawford, 2004).

### **Professional Development as Teacher Change**

Many teacher educators see the purpose of highly effective professional development as three-fold: (a) causing productive change in teacher beliefs and (b) change in classroom practice that led to (c) increases in student achievement. However, teachers often define effective classroom practice almost exclusively by its impact on student achievement. So in order to achieve the first three goals, Guskey (1986) proposed that professional development should first work towards changing teachers’ classroom practice in order to increase student achievement. Only then will the teachers themselves have any change in beliefs or attitudes about teaching. Guskey (1986) proposed a model

of teacher growth that emphasizes the role of student outcomes as the primary motivation for teachers to change their beliefs and attitudes towards pedagogical change. The drawback of Guskey's model is the assumption of a linear process for teacher change. Clarke and Hollingsworth (2002) provided an alternative to the Guskey model with their development of the Interconnected Model of Teacher Professional Growth (IMPG). The IMPG provides a model in which iterative and cyclic teacher change is possible and can be identified.

The IMPG is grounded in the idea that teacher change occurs through the mediating process of reflection and enaction between and within four domains of a teacher's world. The four domains include the personal domain (PD), the domain of practice (DP), the domain of consequence (DC), and the external domain (ED). This model can describe the various ways teachers change through identifying the unique sequence of mediating processes of reflection and enaction a teacher engages in as changes occur. For example, after a professional development experience (external domain), some teachers may not begin with changes in practice (domain of practice) directly but first anticipate the impact on student learning (domain of consequence). Still other teachers may be more inclined to wrestle with their personal beliefs about teaching and content (personal domain) before considering changing their practice (domain of practice).

Clarke and Hollingsworth (2002) suggested that the IMPG could be used as an analytical, predictive, or interrogatory tool. In response to this suggestion, Justi and Van Driel (2006) used the IMPG as a framework for designing a professional development project to promote teacher's understanding of scientific models and model-based



instruction. They also used the IMPG as a framework for the analysis of the data they collected. They found that as an analytical tool, the IMPG “made it possible to understand each teacher’s development in a detailed way” (Justi & Van Driel, 2006, p. 448-449.). In another study, Neilson (2012) used the IMPG as an analytical tool in her study focused on science teachers’ meaning making when they collaboratively analyze artifacts from practice. While Neilson did not use the IMPG as a PD planning tool, her use of the IMPG framework as an analysis tool supported the findings of Justi and Van Driel (2006) that the framework was especially effective for making sense of complex processes associated with teacher learning and teacher change. The IMPG framework will be further explicated in Chapter 3 of this study.

## CHAPTER 3

### METHODS

In this chapter, I will first provide an overview of the methodological approach I employed for this study. I will then provide more detailed descriptions of the participants, the professional development institute in which they participated, and the quantitative methods I used to identify each participant's Knowledge of Scientific Models and Modeling (KSM), their use of questioning to facilitate classroom discourse, and their knowledge of the Nature of Science (NOS) for the first part of this study. I will also discuss how these characteristics were statistically analyzed and compared to their ability to implement Model-Based Teaching (MBT). I will then describe the methods I used in the second part of this study to generate three case studies and conduct a cross case analysis. I will conclude the chapter with a discussion of the how this study addressed the issues of validity, reliability, and generalizability.

This research has been conducted from a constructivist perspective. In the field of education, two preeminent paradigms of student learning, cognitive constructivism and social constructivism, are especially useful when framing questions to be answered by a qualitative study. From the cognitive constructivist viewpoint, learning is an internal process where people build meaning through experiences with the environment

(Piaget, 1985). The social constructivist perspective describes the learning process as the development of subjective meanings for the things people see and experience in the world is done through interaction with others (Vygotsky, 1978).

An integrated view might be that learning is both an internal process and a social one (Windschitl, 2002). The act of trying to integrate two different perspectives tends to lead to complex questions with even more complex answers. As a result, education researchers tend to look for the complexity that explains these meanings rather than a simplification of the meanings through categorization and classification. This leads researchers to investigate questions that focus on the “processes” of interaction between individuals (Flyvbjerg, 2011). For these types of studies, a qualitative design can provide a rich description of these complex processes. Furthermore, qualitative data can be used to precisely identify which events led to what outcomes and follow up with a rich description of why those events had those consequences (Miles & Huberman, 1994).

In qualitative research, depending on one’s theoretical framework, the appropriate questions to investigate often arise only after a considerable amount of data have been collected and analyzed. However, guiding questions about the issues or concepts that are interesting can serve to guide the researcher in the collection of data (Nagy Hess-Biber & Leavy, 2011). Within the literature on the challenges associated with implementing inquiry learning and the effectiveness of model-based teaching on student learning, studies describing the professional development of in-service teachers that is focused on how teachers learn to implement Model-Based Teaching in their classroom was in short supply. After considerable time reviewing the literature on what teachers need to know

and be able to do when implementing model-based teaching, the following guiding questions were identified:

1. In what ways do teachers' views of the Nature of Science (NOS) impact their ability to implement model-based teaching?
2. In what ways does teachers' use of questioning to facilitate classroom discourse impact their ability to implement model-based teaching?
3. In what ways do teachers' knowledge of scientific models and modeling impact their ability to implement model-based teaching?

In this study, the research questions focus generally on gaining a better understanding of how teachers incorporate a new teaching strategy into their teaching and more specifically on the salient challenges and dynamics of implementing a specific strategy described here as Model-Based Teaching (MBT). MBT engages students in activities that approximate the authentic scientific practice of Scientific Modeling. In doing so, students not only learn the disciplinary core ideas of science but also gain a deeper understanding of the nature and processes of science (NRC, 2011a).

Due to the complexity of the research questions and the particular constructivist perspective with which this study was conducted, a mixed method approach was selected. Mixed methods studies have been widely used to gain better understandings of the processes associated with high quality science teaching. A mixed methods approach affords stronger inferences than a quantitative or qualitative only approach (Creswell, 2003).

Part one of this study is a quantitative investigation into the statistical relationships between the independent variable, each participating teachers' ability to

implement MBT in the middle or secondary science classroom and the dependent variables associated with each teacher's, (a) knowledge of Scientific Models and Scientific Modeling, (b) beliefs about the tentative, iterative, and creative Nature of Science, and (c) ability to facilitate classroom discourse through questioning.

These variables were assessed using four instruments, one for each variable listed above. For part 1, online questionnaires were used to collect data on the participating teachers' Knowledge of Scientific Models (KSM) and understanding of the Nature of Science (NOS). Descriptive rubrics in the form of observation protocols and performance progressions were used to analyze video and observation data on each participating teacher's facilitation of classroom discourse through questioning and their implementation of MBT. Non-parametric statistical analysis was used to identify relationships between the 3 independent variables and the dependent variable. The results of this quantitative analysis helped to guide the second, qualitative portion of the study.

The second, qualitative portion of this study employed a collective case study approach in which in-depth case studies were completed for purposefully selected participating teachers. This part of the study aimed to understand how teachers develop the ability to implement Model Based Teaching (MBT) and to further investigate how the three factors from part one of the study contribute to their implementation of MBT in their own classroom. The Interconnected Model of Teacher Professional Growth (IMPG) (Clarke & Hollingsworth, 2002) was used as a framework for the analysis of the various sources of qualitative data collected before, during, and after the summer institute. Data sources included pre-institute surveys, institute daily reflections, transcripts of video of sessions from the institute, post institute interviews, post institute classroom observations

and the semi structured interviews conducted before and after the observations when available.

Since many of the various data sources for this study will be analyzed in both qualitative and quantitative ways, a Concurrent Nested Strategy of data collection and analysis, as described by Creswell (2003), was employed. Concurrent Nested Strategy is exemplified by the collection of both quantitative and qualitative data simultaneously. The nested quantitative data is given less priority while the predominant strategy, in this case qualitative data collection, is emphasized. Using this method allows for the identification of significant correlations between the predictor variables of teacher knowledge, abilities, and beliefs and the dependent variable, implementation of model based teaching through the use of appropriate statistical methods. Qualitative analysis then illuminates the particular nuances and underlying inferred causes of the correlations identified through quantitative analysis. The qualitative analysis also provided a more in-depth look at how teachers are progressing through the process of learning how to successfully implement MBT.

### **Participants**

The 15 participating teachers came primarily from rural and suburban high schools and middle schools in South Carolina. This group of teachers mean teaching experience was 14 years and ranged from 0 to 39 years with eleven teaching primarily high school and four teaching primarily middle school (Table 3.1). Eight teachers had master's degrees in education, one teacher had a master's degree in science, and the remaining six teachers had bachelor's degrees in science or education. Six teachers taught biology, four teachers taught physics or physical science, two teachers taught chemistry,

one teacher taught earth science, and three teachers taught eighth-grade science or earth science.

Table 3.1

*Summary of Participating Teachers' Context*

<b>Name</b>	<b>School</b>	<b>Course</b>	<b>Years Experience</b>
Sarah	MS	8th grade science	0
Christina	MS	8th grade science	2
Jeanie	MS	Earth Science	14
Carla	MS	biology	11
Barry	HS	physics	33
Andy	HS	Physics	8
Alan	HS	physical science	39
Laurel	HS	physical science	4
Henry	HS	chemistry	14
Denise	HS	chemistry	16
Rachael	HS	biology	5
Debra	HS	biology	36
Justine	HS	Biology	5
Maggie	HS	biology	11
Patti	County Science Specialist	biology	10

All 15 teachers participated in a one-week summer professional development institute provided as part of this research project. Recruitment efforts specified that

teachers have experience teaching and be scheduled to teach one of four courses in the school year immediately following the summer staff development institute; biology, chemistry, physics, or physical science. Recruitment of teachers began with the generation of a digital flyer and application that was e-mailed to school district principals, science specialists, and science department chairs. The flyer and application specified that teachers would need to (a) video record a classroom lesson or activity that in any way incorporated the use or discussion of scientific models, (b) complete the application, (c) participate in the summer professional development institute, (d) enact one lesson from the institute in their classrooms in the first semester of the school year following the staff development institute, and (e) attend two Saturday workshops in the same subsequent semester.

Due to funding constraints, the study population was to be limited to 20 teachers recruited from the high school science teachers employed in South Carolina. All teachers who were currently teaching high school biology, chemistry, physics, or physical science were potential participants. If more than 20 teachers had applied, selection would have been based on a purposeful sampling strategy described as a Maximum Variation Strategy (Patton, 2002) . In this approach, participants are selected that differ significantly from all other participants in the study. While having a small sample group can be a limiting factor to a study, purposefully selecting for diversity has the benefit of yielding high quality, detailed descriptions of unique cases (extreme, critical, typical, or intense) while also allowing for the identification of shared patterns that span the diverse group. As it turned out, only 15 teachers applied for the institute and two were middle school teachers resulting in a convenience sample. A convenience sample is the least



desirable but still affords the opportunity to look for cases that warrant in-depth analysis (Patton, 2002). Three teachers, Laurel, Andy, and Carla, were selected as cases from the pool of 15 teachers. These cases were selected as representatives of three stages of a trajectory in the implementation of model based teaching, a trajectory of teacher growth proposed by the findings of this study.

### **Professional Development Overview**

The summer professional development institute provided a one-week University of South Carolina grant funded course of activities for secondary science teachers. The goals of the professional development institute were as follows:

1. Provide measureable improvements in participating teachers' knowledge of Scientific Models and the process of Modeling.
2. Provide measurable improvement in participating teachers' use of classroom discourse, in particular, their use of questioning.
3. Deepen participating teachers' understanding of the Nature of Science and the processes of science, namely Scientific Modeling.
4. Facilitate the construction, modification, and implementation of Model Based Teaching lessons in the secondary and middle school science classroom.

The professional development institute was led by two lead teachers, experienced in model based inquiry instruction, and two researchers (a science education professor and me). One of the lead teachers was a graduate student and full time high school physics teacher who used the Modeling Instruction framework (Hestenes, 1996) as his primary method of teaching. He had led several modeling workshops prior to this summer institute. The other lead teacher was a recent PhD graduate in curriculum and instruction

who worked for several years on various research projects focused on understanding students' use of models and modeling at the elementary and middle school level as well as supporting pre-service teachers in learning about modeling as a pedagogical approach (Kenyon, et al., 2011).

Due to funding constraints, the institute was limited to one week but the professional development plan was ambitious. Each day consisted of four, one and one half hour sessions separated by two fifteen minute breaks and a forty-five minute lunch. Each session consisted of one or more of three types of activities; administrative activities, whole group activities, or small group (subject specific) activities. Administrative activities included the completion of paperwork for the institute, pre and post-institute surveys, questionnaires, and interviews for data collection, and time for daily reflection, Q &A sessions, or time for needed adjustments to the institute schedule.

On Days 1–3 of the institute, whole group activities were conducted by lead teachers. These whole group sessions focused on themes that cut across disciplines. For example, the first session was an introduction to model based teaching through engagement in a solar system lesson. During the second session whole group activity was a modeling lesson focused on the Nature of Science. These sessions engaged participating teachers in content specific modeling lessons as “teacher-students”. They experienced what it is like to learn content standards through model-based teaching. These whole group sessions were followed by small group, content specific sessions. Prior to the institute, participants selected content areas (physics, chemistry, or biology) specific to their own teaching assignments. Small group sessions were organized for these content groups and focused on content topics within each discipline. The physics

group focused on acceleration, the chemistry group focused on properties of gases, and the biology group focused on cellular reproduction. While the whole group sessions utilized lessons that could be completed in one or two class periods, these small group sessions provided an opportunity for teachers to see how a modeling unit could be developed and implemented over the course of multiple class periods. For example, the teachers in the biology group were engaged in a modeling lesson that focused on developing an explanation of cellular reproduction via mitosis. The lesson began with discussion about growth of organisms and led to describing plant roots as a place where cells would be growing. This was followed by time to observe the cells of an onion root tip using a microscope and create drawings of the different cells that could be seen. “Students” then looked for patterns in the drawings and generated an explanation for those patterns. They drew explanatory models on whiteboards, shared them with their peers, and revised them based on the discussion. The target model was an explanatory model that could account for the changes they were seeing in the nucleus and identify a causal mechanism for how cells make copies of themselves that are identical. This series of activities were completed over the course of 4.5 hours at the institute but represented 1–2 weeks of class time in a typical high school biology classroom.

Table 3.2

*Summer Professional Development Schedule*

Mon	Tue	Wed	Thu	Fri
<b>Session 1.1</b>	<b>Session 2.1</b>	<b>Session 3.1</b>	<b>Session 4.1</b>	<b>Session 5.1</b>
Introductions, surveys, interviews, paperwork.	Modeling Lesson: Using a Model based approach to teaching about the Nature of Science	Subject Specific Modeling Lesson focused on content, NOS, discourse, etc.	Lesson Planning	Participant-Led Modeling Lesson
				Debrief
<b>Break (15 min)</b>	<b>Break</b>	<b>Break</b>	<b>Break</b>	<b>Break</b>
<b>Session 1.2</b>	<b>Session 2.2</b>	<b>Session 3.2</b>	<b>Session 4.2</b>	<b>Session 5.2</b>
Modeling Lesson: Model-Based Inquiry and Model-Based Learning	De-briefing the Lesson: Process of Science and the Nature of Science	De-briefing the Lesson: Time to work on Lesson	Participant Led Modeling Lesson	Participant Led Modeling Lesson
			Debrief	Debrief
<b>Lunch (45 min)</b>	<b>Lunch</b>	<b>Lunch</b>	<b>Lunch</b>	<b>Lunch</b>
<b>Session 1.3</b>	<b>Session 2.3</b>	<b>Session 3.3</b>	<b>Session 4.3</b>	<b>Session 5.3</b>
De-briefing the Lesson: Knowledge of Scientific Models and Modeling	Subject Specific Modeling Lesson focused on classroom discourse	Subject Specific Modeling Lesson focused on content, NOS, discourse, etc	Participant Led Modeling Lesson	Participant Led Modeling Lesson
			Debrief	Debrief
<b>Break (15 min)</b>	<b>Break</b>	<b>Break</b>	<b>Break</b>	<b>Break</b>
<b>Session 1.4</b>	<b>Session 2.4</b>	<b>Session 3.4</b>	<b>Session 4.4</b>	<b>Session 5.4</b>
Introduction to Lesson Assignment Steps for Modifying Lessons to be more inquiry/modeling based	De-briefing the Lesson: Time for lesson planning	Debrief - Time for Lesson Development	Participant Led Modeling Lesson	Exit Survey Exit Interviews, surveys, etc.
			Debrief	
<b>Reflection Time</b>	<b>Reflection Time</b>	<b>Reflection Time</b>	<b>Reflection Time</b>	<b>Reflection Time</b>

Each of these model based content sessions were followed by a period of time for de-briefing the lesson and presentation of pedagogical strategies and metamodeling knowledge discussions (Kenyon et al., 2011). Subject specific group activities were split between subject specific model lessons, debriefing sessions, and planning time for teachers to work in small groups on developing lessons that they implemented on the last two days of the institute as well as in their classrooms in the subsequent school year. The institute schedule is summarized in Table 3.2 above.

### **Academic Year Workshops**

During the school year following the summer institute, participating teachers were invited to attend a Saturday workshop during the fall semester. The workshop was held in the same location as the summer institute and provided participants a chance to experience an additional modeling lesson as well as discuss and/or refine their lessons to be implemented in their own classrooms. Five of the original participating teachers attended the Saturday workshop. Two of the three case study teachers were in attendance at this workshop.

### **Part 1: Nested Quantitative Analysis**

Due to the qualitative nature of the majority of the data being collected for this research study, data analysis began immediately upon receiving the completed pre institute surveys, questionnaires, and videotapes and continued throughout the duration of the semester following the summer institute. Due to the varied forms of analysis, the specific data sources that were analyzed quantitatively will be described first and then a description of the qualitative analysis methods used in part two will follow.

Data collection began when participants submitted a videotape of a classroom lesson in which they have used or discussed scientific models. In addition to the submission of classroom videos, teachers completed the Views on Science Education (VOSE) questionnaire, portions of the View of Nature of Science form C questionnaire, and the Knowledge of Scientific Models (KSM) survey prior to attending the institute. The VOSE questionnaire uses a Likert-scale to assess teachers' views of the Nature of Science (NOS) (Chen, 2006) and the VNOS-C is an open ended response survey that also assesses views and understandings of NOS. The Knowledge of Scientific Models (KSM) survey is an online questionnaire that will be used to determine the teachers' current knowledge of the role of models and modeling in science and science education (Bogiages, 2009). Using a categorical coding scheme, quantitative data was generated that allowed for the establishment of a correlation between the teachers' knowledge of scientific models and modeling, ability to use questioning to guide inquiry, and views of the Nature of Science on their implementation of MBI. The data collected from these assessment instruments were analyzed using non-parametric statistical analysis. A Spearman rank order was used to identify any significant correlation between each teacher characteristic and their implementation of the model-based inquiry pedagogy as measured by the Teacher's Performance Progression for MBI (Thompson et al., 2009). Since the majority of the data being collected in this study is qualitative in nature, evaluation instruments that could help transform qualitative data into quantitative data were needed. In the next section, I will describe the selection of each instrument and their associated affordances and limitations.

## **Determining Participants' Knowledge of Scientific Models (KSM)**

All 15 teachers' knowledge of scientific models was assessed before and after the summer professional development institute using an online questionnaire, the Knowledge of Scientific Models and Modeling (KSM) survey (Bogiages, n. d.) (Appendix A). The development of the KSM survey was based on the work of several previous studies which used different instruments to identify participants' (a) understanding of the nature of scientific models, (b) understanding of the process of modeling, and (c) beliefs about teaching with models and through modeling (Crawford & Cullin, 2004; Driel & Verloop, 1999; Grosslight et al., 1991; Justi & Gilbert, 2002b; Schwarz & White, 2005) Participants in these studies included students, teachers, and experts. However, no one instrument found in the literature addressed all three of these goals for teachers. I felt it was necessary to develop an instrument that could better articulate the differences between teachers' understanding of models and modeling suggested to exist by the Van Driel and Verloop (1999) study. The questions required respondents to discuss their understanding of the nature of scientific models and the role models and modeling in science and in science education. The questions were aligned with the four themes identified by Grosslight, Unger, Jay, and Smith (1991) as relevant to the use of models in science education; types of models, characteristics of models, goals and function of models, and modeling in science.

During the piloting of early versions of the KSM survey prior to this research, responses were vague and broad and did not lead to a rich description of teachers' knowledge of models nor were responses easy to differentiate from other respondents. However, upon making several changes in a second round of piloting, mainly by further

developing each question and incorporating specific questions from the multiple studies listed above, participant responses became more specific and as a result, more easily differentiated from other respondents. In its current form, the KSM survey is intended for use with in-service classroom teachers but could likely be used with pre-service teachers with few modifications.

The KSM was administered before and immediately following the summer institute. Three questions, numbered 5, 7, and 8, (see Appendix A) were omitted from the post institute survey because they asked about the respondents' use of models in the classroom. Due to the timing of the institute being in the summer, teachers would not have been able to report any change in their teaching in response to these questions and would consider answering these questions again to be unnecessary. The pre and post institute responses were the primary source of data to be used to evaluate a participating teacher's knowledge of scientific models and modeling for this study. Secondary and supporting data came from institute daily reflections, utterances during the institute collected by video recording, and pre-lesson interviews (case study teachers only) prior to enacting the modeling lesson in their own classrooms.

The analysis of teachers' responses to the KSM was an iterative process involving multiple rounds of coding. Before coding began, a preliminary descriptive rubric with operationalized constructs was developed to assess the levels of understanding of the nature of models and levels of thinking about models that reflect a person's epistemological view about models and their use in science and in science education. The rubric was initially based on the findings of the studies described above. When taken together, the literature was helpful in articulating the differences in the responses between



the levels of knowledge of models across four dimensions of modeling knowledge. However, during the analysis of participant responses, the descriptive rubric was reorganized to specifically measure a respondent's knowledge of scientific models and modeling in terms of three dimensions that emerged from the coding of responses. These dimensions include The Nature of Models and Modeling (Dimension 1), Connections Between Scientific Models and the Nature of Science (Dimension 2), and Connections between Scientific Models and Teaching (Dimension 3). During the analysis of the responses, further changes were made to the rubric, providing finer articulation of each level of each dimension.

As a result, the final KSM scoring guide (Appendix B) is a descriptive rubric that identifies a teacher's level of knowledge of three domains of scientific modeling knowledge. Each domain can be assigned a score ranging from 1 to 4. A score of one indicates a minimal and limited knowledge level of that particular dimension of knowledge about scientific models. A score of two indicates a teacher has a typical (naïve or simple) understanding of scientific models and modeling. (As the literature suggests, a naïve understanding is the typical level for most science teachers.) A score of three indicates a teacher has a proficient understanding of models and modeling and a score of four indicates a teacher has an informed, expert-like understanding of scientific models. An informed understanding is similar to the understanding of experts as defined by Grosslight, Unger, Smith, and Jay's (1991) level three. A participant's scores in each of the three dimensions were then averaged in order to produce an overall score for modeling knowledge.

## **Determining Participants' Understanding of the Nature of Science**

Teachers' understandings about the Nature of Science are important factors that impact their ability to implement model-based teaching (Danusso, et al., 2010; Henze, et al., 2007). A teacher's understanding of the relationships between hypothesis, theory, and law, as situated within their understanding of the NOS, is a general indicator of their sense of the structure of scientific knowledge. A teacher's understanding of the tentative and imaginative aspects of NOS indicates their sense of how scientific knowledge is generated. Understanding how scientific knowledge is generated is especially important when teachers are attempting to implement model-based teaching (Windschitl, Thomson, et al., 2008).

For this study, I employed the use of two survey instruments that provide information about a teacher's views and understandings about the Nature of Science NOS. The Views on Science and Education (VOSE) (Chen, 2006) questionnaire was administered to all participants prior to the summer professional development institute. This instrument provided a numerical score derived from Likert-type questions, which focused on multiple aspects of the NOS. I also employed the use of an abbreviated version of the Views of the Nature of Science (VNOS-C) questionnaire (Lederman, et al., 2002) which is a survey that consists of open-ended response type questions.

The VOSE was developed for the purpose of creating in-depth profiles of adults views of the NOS and NOS instruction (Chen, 2006). This allows it to be used in comparison studies such as this one, to relate a person's views of NOS to other measurable educational outcomes, which in this study, is the implementation of model-based teaching. The VOSE consists of 15 questions, each followed by several statements

that depict a particular philosophical position. Participants are instructed to rank each statement on a Likert-scale of 1–5.

Interpreting participant responses to the VOSE questionnaire began by calculating a score for each question’s response. Response scores can range from 1 to 5. A 1 indicates the respondent strongly disagrees with that aspect of the NOS, a 2 would indicate disagrees, a 3 would indicate neither agrees nor disagrees, a 4 indicates the respondent agrees, and a 5 indicates a respondent strongly agrees with that particular aspect of the NOS. For example, Question 3 on the VOSE asks participants:

3. When scientists are conducting scientific research, will they use their imagination?
  - A. Yes, imagination is the main source of innovation.
  - B. Yes, scientists use their imagination more or less in scientific research.
  - C. No, imagination is not consistent with the logical principles of science.
  - D. No, imagination may become a means for a scientist to prove his point at all costs.
  - E. No, imagination lacks reliability.

Statements A” and “B” are positive statements that align with an accepted view of the imaginative aspects of the NOS. Statements “C”, “D”, and “E” do not align with the accepted view of the imaginative aspects of the NOS. In order to score a participant’s response to a VOSE question like this one, the responses for “A” and “B” are considered positive values and the responses to C, D and E are considered negative values and are inverted. For example, if a participant were to score the statements for question 3 as 4,4,1,2, 3, this would be summed as  $4+4+5+4+3=20$ . A score of 3, being neither a

negative nor a positive response, would remain a 3. The sum would then be divided by the number of statements in the question, thus arriving at a collective score for that aspect of the NOS that is the focus of the question. So for the example above, which is focused on the imaginative aspects of the NOS, the response would be scored as  $20/5 = 4$ . A score of 4 on any item in the VOSE would be considered as an “agree” response. In this case, the respondent agrees that NOS has an imaginative aspect.

I anticipated that the VOSE scores would be useful for the quantitative portion of this study but would not be as useful in the qualitative portion of the study without. In other words, further clarification to responses on the VOSE would be needed. This supplemental, qualitative data on the participating teachers’ views of the NOS were collected using the Views of the Nature of Science (VNOS-C) questionnaire (Lederman, et al., 2002). In this study, I used the VNOS-C version of the questionnaire. VNOS-C was revised and expanded to include questions that aimed at assessing the belief in the existence of a universal scientific method held by teachers. This form consists of a series of open-response questions developed to elicit teachers’ views of the NOS. Specific questions from this instrument were selected based on their alignment with the aspects of the NOS that were deemed most relevant to a teacher’s ability to implement model-based teaching. Of the ten questions on the VNOS-C questionnaire, the following were chosen to include in this research as they directly relate to the findings of my literature review with regard to the implementation of model based teaching and the nature of scientific models identified by Crawford and Cullen (2004).

1. What, in your view, is science? What makes science (or a scientific discipline such as a physics, biology, etc.) different from other disciplines of inquiry (religion, philosophy)?
2. After scientists have developed a scientific theory (e.g. atomic theory, evolution theory), does the theory ever change?
  - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
  - If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.
3. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulate by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the Earth 65 million years ago and led to a series of events that caused the extinction. A second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions [emphasis in original document]?
4. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?

- If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
- If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

Upon completing the VNOS-C questionnaire, the authors suggest conducting semi-structured interviews with 15 -20% of the participants for a given study in order to clarify participants' responses and establish validity of the assessment of the VNOS-C responses (Lederman, et al., 2002). During these interviews, respondents are asked to describe their answers to the questions in further detail, by clarifying the terms they used, providing examples that supported their statements and justifications for their responses.

Analysis began by establishing contextual meaning to the key terms and phrases used by respondents. I then compared responses to the descriptions of each related aspect of the Nature of Science described by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). I then established internal consistency for each relevant aspect of the NOS by comparing participant's responses to different questions. Authors of the VNOS-C state that the questions on the VNOS-C do not aim to have a one-to-one correspondence to aspects of NOS. For example, the authors of the VNOS-C have indicated items 4 and 10 largely target respondents' views of the tentative and creative NOS. However, this does not mean that other questionnaire items could not elicit meaningful statements about these aspects. Based on this analysis, response profiles were generated and assigned a

level of naïve, transitional, or informed for each participant's level of understanding of the NOS.

Based on the suggestion from the authors of the VNOS-C (Lederman et al., 2002), I conducted follow up interviews with 5 of the 15 participants (33%). During these follow-up interviews, participants were asked to respond to clarifying questions about statements they made in their VNOS-C responses. These 5 participants were purposely chosen, also suggested by Lederman (2002), based on their availability following the institute and their participation in the implementation of model based teaching in their classroom during the school year following the summer institute. I then applied the same analysis process to the follow-up interview transcripts in order to establish consistency between each participant's questionnaire responses and their interview responses.

While the developers of the VNOS-C state that it is preferable to administer the questionnaire under controlled conditions, due to time and distance constraints the VNOS-C questionnaire was administered via an online survey tool for this study. As advised by the authors of the VNOS-C questionnaire, instructions were provided within the online survey to participants that reminded them there were no right or wrong answers and that they were encouraged to write as much as they can in response to each item, providing examples when appropriate.

In order to align the data collected from the VNOS-C and the VOSE, open-ended responses from the VNOS-C, were paired with the numerical scores from corresponding items from the VOSE when possible (Appendix E). The numerical VOSE scores were aligned with the classification scheme suggested by Lederman and others (2002) and used by Herman, Clough, and Olsen (2013). Herman et al. (2013) assigned the

classifications of “naïve”, “transitional” and “informed” views about the NOS to participants. An “informed” view was assigned to participants whose views about aspects of the NOS, as determined by the VOSE, were found to have a 70% congruence with the accepted views described in the literature (Herman, Clough, and Olsen, 2013, pp 1086-1087). The “naïve” designation was assigned to those participants whose views were 70% not in congruence with accepted views of the NOS. This scoring was aligned with the 1-5 range of scores on the VOSE questions by assigning the “informed” classification to those scores at or above 3.8 which would represent 70% congruence with the accepted view of that aspect of the NOS. Likewise, the “naïve” designation was assigned to those responses that scored at or below 2.2 on the VOSE scale which would represent 70% incongruence with the accepted views of that aspect of the NOS. The “transitional” designation was assigned to those whose views did not fall in either the naïve or informed ranges.

The authors of the VNOS-C suggest that low inference is desired throughout the analysis of responses. Using multiple sources allowed for a check on the depth of participants’ understanding of that particular aspect of the NOS. For example, if their responses are consistent across the questions of the VNOS-C and the VOSE, it can be reasonably inferred that an accurate picture of their understanding of these aspects of NOS can be declared. This pairing contributed to the validity of the assessment of a participating teacher’s view of NOS as being naïve, transitional, or informed.

For the quantitative analysis used in part one of this study, decisions were made to assign a participant’s views and understandings of the NOS a score ranging from 1 to 4. A score of 1 indicated a participant had an uninformed view of the NOS. A score of 4



indicated a participant had an informed view of the NOS. The transitional profile was subdivided into two possible quantitative scores. A transitional profile that was slightly more informed than a naïve understanding was assigned a score of 2 indicated a developing understanding of NOS. A transitional profile that was slightly less informed than an informed understanding was assigned a score of 3 indicated a more proficient level of understanding of the NOS. This departure from the generally accepted scoring was done to facilitate the quantitative analysis.

### **Determining the Level of Teacher Questioning**

In order to assess the ability of the participants in this study to use questioning as a means of guiding model –based teaching, an observation instrument was needed that focused on multiple facets of teachers’ use of questioning during instructional activities. Several instruments were reviewed for their ability to articulate a teacher’s use of questioning. After considering the options, the Electronic Quality of Inquiry Protocol (EQUIP) (Marshall, Smart, & Horton, 2010) was chosen. The EQUIP is an observation instrument designed to measure the quantity and quality of inquiry instruction. The EQUIP uses four descriptive rubrics that afford raters a more systematic and less subjective means of rating during observations thus improving the instruments reliability. Each rubric contains operationalized indicators of multiple sub-domains within the focus subscales of each rubric. These operationalized indicators provide a numerical representation of teachers’ current inquiry practice on the instrument’s four subscales; curriculum, discourse, instruction, and assessment. The discourse rubric (Appendix C) of the EQUIP, which was used for this study, primarily focuses on questioning using five sub-domains; questioning level, complexity of questions, questioning ecology,

communication patterns, and classroom interactions. Each of these sub-domains can be scored at 4 levels using this instrument; pre-inquiry, developing inquiry, proficient inquiry, and exemplary inquiry. Each score for each sub-domain was then averaged with the scores from the other subdomains within the rubric. The resulting average was then rounded to the nearest whole number, providing a single number between 1 and 4 for each participant, representing each participant's score in that sub-scale, in this case the use of questioning to support discourse. While the authors suggest that the summative score for any subscale should capture the "essence" of the observation and may not always strictly be the mean of each sub-domain, the findings in this study were aligned with the mean score for each participant.

Video of teachers enacting model-based teaching was collected at multiple points during this study. Several participants submitted a videotape of a classroom lesson in which they had used or discussed scientific models prior to the summer institute. Video was also recorded during the summer institute when participants enacted their group-developed modeling lessons. When available, participants post institute classroom enactments of model-based teaching were also recorded. These data sources were analyzed using the EQUIP (Marshall, et al., 2010). Before using the discourse portion of the EQUIP on my own data, I watched a training webinar available at the Author's website. I then used the discourse rubric to assess the discourse factors of three videos available on the TIMMS website. These videos had also been scored using the EQUIP by the author of the instrument. The expert scores were used as a baseline for establishing inter-rater reliability for my study. Upon scoring the 3 videos, an inter-rater reliability of 100% in the summative score for each video was achieved. While there was some

variability between each sub-domain score and the expert scores of individual sub-domains, the process of calculating the final score for the whole video in the dimension of discourse removed this variability in the scores.

### **Determining the Level of Implementation of Model-Based Teaching**

With the relative success and ease of use I had with the EQUIP's use of a descriptive rubric, I returned to the literature in search of a descriptive rubric that could be used for the assessment of a teacher's implementation of model based teaching. I selected the Performance Progression for Model Based Inquiry (PPMBI) (Thompson, et al., 2009) for this work (Appendix D). The development of PPMBI was based on the identification of authentic disciplinary practices in science, how students learn science, and novice teacher development. The performance progression differs from other learning progressions in that it is not based on teacher knowledge but on teacher performance of Model-Based Inquiry (Thompson, et al., 2009). This performance progression is composed of a continuum of pedagogical sophistication along 11 different dimensions of reformed teaching that support MBI. This progression is based on the study of novice teachers' progression of practice over several years, making it different from a typical novice-expert dichotomous progression where the intervening levels of sophistication are hypothesized. This difference makes it especially useful for this study, which attempts to identify how the three factors within my research questions play out in my participants' progression in implementing Model-Based Teaching. The full progression of 11 dimensions was condensed by the authors into a four-category progression for facilitating use with teachers. The condensed PPMBI identifies four levels of increasing performance sophistication through the evaluation of a teacher's

ability to (a) select ideas and treat them as models , (b) attend to students' ideas as they arise in discussion, (c) choose activities that facilitate MBI, and (d) press students for evidence based arguments.

Scoring a teacher's performance was completed in a similar way as the calculation of the summative score on the EQUIP. Videos of teaching were viewed and analyzed using the PPMBI for each participant. Scores were assigned to each video for each of the four categories in the progression. Each category describes a progression of sophistication of teachers' abilities. Based on the level of sophistication of a teacher's implementation, a score was given to each category on a scale of 1 to 4. A score of 1 indicated an unsophisticated level of implementation. A score of 2 in any category indicated a developing level of sophistication. A score of 3 indicated a proficient level of sophistication and a score of 4 would indicate a sophisticated, expert-like, level of implementation of model-based teaching. Scores in each category were averaged to generate an overall score for each participant's level of sophistication when implementing model-based teaching. This overall score, while not informative in a qualitative way, was useful for the statistical analysis associated with part 1 of this study and was based solely on the institute lessons and the post institute lessons when available.

Two of the four categories in the progression—selecting big ideas and treating them as models and attending to students' ideas—have only three separate levels of sophistication. For these two categories, the upper level of the progression was scored as a 3 for achieving one of the indicators in that level and a score of 4 was given if 2 or more indicators from the upper level were identified.

After reviewing the data generated by the instruments explicated in the previous section, it was noted that there might be some similarities between the instruments that could lead to a false sense of correlation between them. In particular, the EQUIP instrument with its focus on questioning, and the MBI progression with its focus on reformed teaching could potentially measure the same aspects of a teachers performance in the classroom. In order to address this possible confounding situation, careful attention to what was being measured was employed.

For example, in Dimension 2 of the EQUIP discourse instrument, Complexity of Questions, the highest level identifies teacher performance associated with “questions required students to explain, reason, and/or justify. Students were expected to critique other’s responses.” On the MBI progression, the word “justify” is used in the lowest category of teacher performance in “pressing for explanation”. When using the EQUIP, the complexity of questions was interpreted as pushing students to explain their responses to questions posed by the teacher or other students. When using the MBI progression, these explanations were further analyzed for what the student included in their explanation in terms of answering, “what”, “how”, and “why”. While simply pressing students for further developing their response was valued by the EQUIP, the MBI progression, being more focused on the epistemic reasoning of the student, took the analysis of that response further. It might be argued that engaging in questioning facilitates many forms of classroom inquiry, while getting to the “why” is inherent in the questioning that supports Model Based Teaching.

In general, the main difference between the two instruments is that the EQUIP pushes teachers to appropriately use a range of medium and high level questioning to

scaffold student-student dialogue that is conversational and supports scientific argumentation. While this form of dialogue is not completely absent in the MBI classroom, the main push of the MBI progression instrument is on developing students' ability to connect the observable phenomenon under investigation with unobservable causal mechanisms in an effort to promote a view of science as a modeling process. These distinct differences in the two instruments sufficiently differentiate them as measuring separate but similar aspects of a teacher's performance.

### **Part 2: Model-Based Teaching Performance Progression**

The second part of this study is a qualitative study using an interpretive, multi-case study approach (Merriam, 1998). The case study, one particular form of qualitative research, is especially effective at illuminating an in-depth understanding of a situation as well as the meaning of that situation to those involved. Furthermore, the case study is a form of qualitative research that is well suited to generating robust explanations for the observed outcomes (Merriam, 1998). The case study differs from other methods of qualitative research in that it is focused on a bounded system or case. The case can be one individual or a group of individuals. In other words, the case is a single entity with distinct boundaries (Merriam, 1998).

The case study allows the researcher to come close to the phenomenon or understanding being studied. If all people have subjective and nuanced views of reality, and the researcher wants to come to know these views, the close proximity to that which is being researched lends itself to a rich understanding (Flyvbjerg, 2011). Furthermore, if the goal of the researcher is to become an expert on the topic being studied, experts need to have first-hand experiences in order to become experts. The case study affords the

researcher the proximity to the phenomenon that gives the researcher the concrete experiences so that they can become an expert in the understanding of the phenomenon being studied.

For this study, I consider the complex development of teachers' classroom practice and the way in which they progress in their use of model-based instruction as a phenomenon that can be described through case study research. As such, the study of the experiences of multiple teachers in multiple settings is needed in order to understand the different ways in which teachers might begin to implement MBT. Yin (2003) suggests that an advantage of this type of design is to allow one to identify contrasting results for predictable reasons. Since the focus of my research questions was the experience of multiple teachers as they moved through a process, the questions lent themselves to the use of a multiple case study approach as Yin (2003) suggests.

Qualitative studies can be influenced by an understanding that the data goes where it will and the researcher follows the interesting lines of data generating themes and theories that organize and explain the data along the way (Creswell, 2003). This qualitative approach involves a literary form of writing that organizes and summarizes data collected through interviews, observations, and the collection of artifacts. The data from these sources have to be analyzed and creativity must be used to bring them together into a coherent representation of the object or phenomenon that is being studied and described.

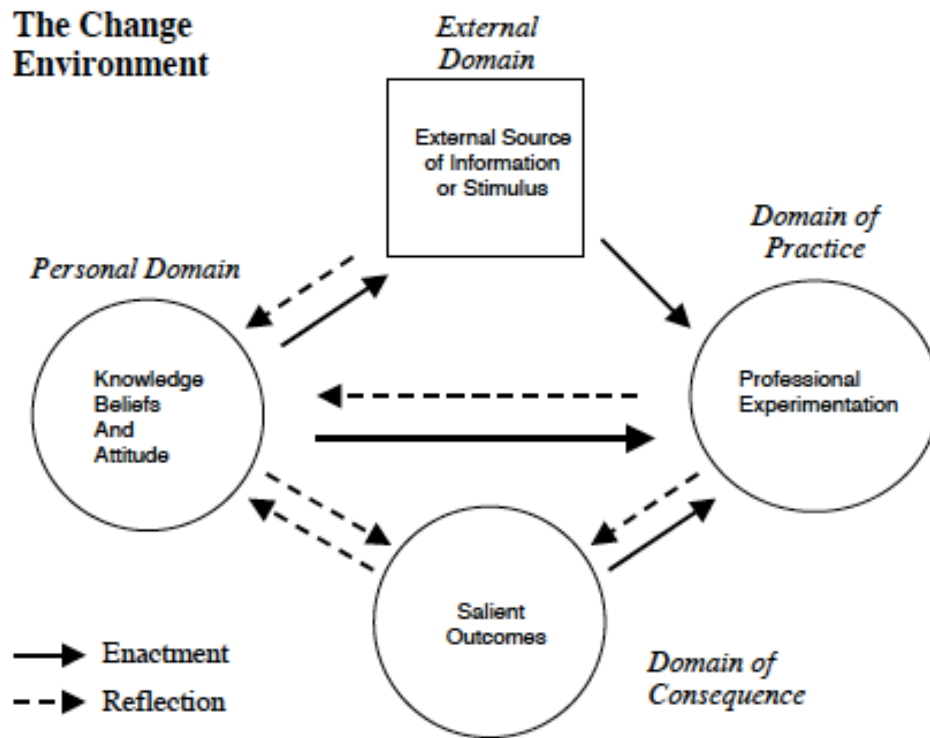


Figure 3.1 The Interconnected Model of Teacher Professional Growth.

Due to the complexity of describing and understanding how teachers implement a new ambitious teaching practice, I sought out an analysis framework that could accommodate a variety of data sources, provide a means for describing the relationships between those data sources, and lend itself to generating rich descriptive cases describing this phenomenon. Furthermore, the framework would need to be able to draw on data for cases within a bounded system, in this case, the teachers who participated in the summer professional development institute and their classrooms (Creswell, 2003). The Interconnected Model of Professional Growth (IMPG) (Clarke & Hollingsworth, 2002) was chosen based on its ability to identify multiple domains of change that foster teacher growth while also describing the processes that mediate change within and between those domains. The IMPG (Figure 3.1) defines a teacher's professional world as consisting of



four distinct domains of change which include the External Domain and three Internal Domains (Personal Domain, Domain of Practice, and the Domain of Consequence). The four Domains are interconnected through the processes of “enaction” and “reflection”. An enaction is a mediating process through which change in one domain instigates change in another domain. Clarke and Hollingsworth (2002, p. 951), distinguish an enaction from simply acting, stating:

The term “enaction” was chosen to distinguish the translation of a belief or a pedagogical model into action from simply “acting”, on the grounds that acting occurs in the domain of practice, and each action represents the enactment of something a teacher knows, believes or has experienced.

In this way, an enaction is an observable action that embodies something a teacher knows or has experienced. Reflection is the practice of thoughtfully considering what has been done or learned. Reflections imply more than a passing recognition of some occurrence. Reflections focus on an occurrence in one domain while drawing on knowledge or beliefs in another domain. As such, reflections are a mediating process in teacher professional growth in that they can lead to future enactments in practice.

These mediating processes originate in one domain and instigate change in another domain. While any one instance of reflection or enaction is unidirectional, it is possible that the same type of mediating process could run in the opposite direction. As such, the mediating process of reflection and enactment serve to interconnect all four domains in the model. This complexity allows for a coherent description of one teacher’s unique growth path as well as a description of the complexity of teacher growth in general. For example, after participating in a professional development activity in which a teacher generates an initial model based on her own preconceptions, she might reflect on how engaging students in generating an initial model could facilitate making student

thinking explicit. This would be coded as a reflection emanating from the External Domain and leading to the Domain of Practice. A reflection is represented by a dotted arrow in the growth network diagram.

According to Clarke and Hollingsworth (2002), sequences of enactions and reflections constitute two different processes in describing a teacher's growth. A series of 1 to 2 enactions or reflections represents a "change sequence" whereas multiple reflections and/or enactions represent a "growth network". Clarke and Hollingsworth (2002) identify the "change sequence" as an empirically supported description of the change that occurs in two domains and the mediating process that connects the changes. A change sequence may be fleeting. If the change is more lasting, as demonstrated to be more than momentary by empirical findings, it is considered a "growth network". This type of change would be indicated by a series of mediating processes, often connecting multiple domains.

In their use of the IMPG, Justi and Van Driel (2006) modify the definition of a "growth network" to be discernible from a change sequence based on the total number of reflections and/or enactions. So rather than basing the distinction on time as Clarke and Hollingsworth did, Justi and Van Driel base the distinction on overall complexity and number of the changes identified. So 1 to 2 relationships would constitute a change sequence while more than 2 relationships would constitute a growth network. For this study, due to the limited amount of time over which data was collected, establishing a growth network based on extended time over which the relationship was observed was not practical. Therefore, the description of a growth network used by Justi and Van Driel

was employed for this study. In this study, teacher growth was monitored over a period of 4 to 6 months thus making Justi and Van Driel's modification appropriate.

Preparing for data analysis required that I first characterize what constituted a teacher implementing model-based teaching in their classroom. Model based teaching aims to engage students in the generation of scientific knowledge through a process that is similar to how real scientists generate knowledge. It is a cyclic and iterative process with four generally identifiable stages, which include constructing, using, evaluating, and revising scientific models (Kenyon, et al., 2011) Khan (2011) identified a coding structure used to identify teacher instructional moves that were associated with the stages of model-based teaching identified by Kenyon et al., 2012. For example, during the constructing a model stage, a teacher might engage students in comparing two aspects or variables within a model would indicate a process associated with generating a model. In this study, these codes were used as an initial guide for identifying the teacher moves associated with model based teaching during the teachers' implementation of model based lessons during the summer PD institute and the classroom observations.

I then had to describe how each mediating process (reflection or enactment) would connect each of the domains in the IMTG. Due to the complexity associated with the interpretation of a teacher's actions, I began by identifying what each type of mediating process between the domains of the IMPG might look like within this study. These descriptions are presented in Table 3.3. These preliminary steps facilitated the subsequent analysis by providing a set of tentative codes to apply to the variety of data sources. This process allowed for the coding of teacher actions as representing a part of the model based teaching cycle and as a mediating process within the IMPG framework.

Table 3.3

*Descriptions of Mediating Processes between Domains of the IMPG*

<b>Originating Domain</b>	<b>Mediating Factor</b>	<b>Domain of Action</b>	<b>Description</b>
External Domain	Reflection	Domain of Practice	When something from the PD Institute instigated a reflection on a participant's own practice.
External Domain	Enaction	Domain of Practice	When something from the PD Institute instigated a change in a participant's practice.
External Domain	Reflection	Personal Domain	When something from the PD Institute instigated a reflection on a participant's knowledge or beliefs.
External Domain	Enaction	Personal Domain	When something from the PD Institute instigated a change in a participant's knowledge or beliefs.
Personal Domain	Reflection	Domain of Practice	When a participant's knowledge or beliefs caused them to reflect on his or her practice.
Personal Domain	Enaction	Domain of Practice	When a participant's knowledge or beliefs caused a change in his or her practice.
Personal Domain	Reflection	External Domain	When a participant's knowledge or beliefs caused them to reflect on activities of the institute.
Personal Domain	Reflection	Domain of Consequence	When a participant's knowledge or beliefs helped them reflect on an outcome.
Personal Domain	Enaction	Domain of Consequence	When a participant's knowledge or beliefs caused a change in student outcomes.
Domain of Practice	Reflection	Domain of Consequence	When a participant's practice instigated a reflection on student outcomes.
Domain of Practice	Enaction	Domain of Consequence	When something that a participant did in their practice caused a specific outcome.

*(continued)*

Table 3.3

*Descriptions of Mediating Processes between Domains of the IMPG (continued)*

<b>Originating Domain</b>	<b>Mediating Factor</b>	<b>Domain of Action</b>	<b>Description</b>
Domain of Practice	Reflection	Personal Domain	When a participant's practice instigated a reflection on his or her own knowledge or beliefs.
Domain of Practice	Enaction	Personal Domain	When a participant's practice instigates changes in his or her knowledge or beliefs
Domain of Practice	Reflection	External Domain	When a participant's practice instigated a reflection on the activities of the PD institute.
Domain of Consequence	Reflection	Domain of Practice	When a student outcome instigated a participant to reflect on their own practice
Domain of Consequence	Enaction	Domain of Practice	When a student outcome instigates a change in a participant's practice
Domain of Consequence	Reflection	Personal Domain	When a participant reflected on his or her own knowledge or beliefs in response to a student outcome.
Domain of Consequence	Enaction	Personal Domain	When a student outcome instigates a change in a participant's knowledge or beliefs

A wide variety of data sources, summarized in Table 3.4, were collected before, during, and immediately following the summer institute. These included the institute applications, survey responses to each of the surveys used in the first part of the study (KSM, VNOS-C, and VOSE), daily reflections generated during the PD institute, and video recordings of practice lessons that occurred during the institute as well as video recordings of the classroom lessons enacted by 5 of the 15 teachers who participated in the PD institute. (Due to logistical constraints, observations for all 15 teachers were not possible.) As a result of the classroom observations, a variety of new data sources were generated for this part of the study including video of classroom lessons, field notes from in-person observations, transcribed interviews before and following the classroom

observations, and follow up phone call interviews that clarified each teachers actions or statements during the lessons or interviews. Observations and video recordings were completed in-person for three of these teachers while two teachers recorded video of their own modeling lessons and submitted the video to me. I generated detailed field notes during the in-person observations and while watching the videos of the classroom lessons for the first time. I then reviewed the classroom videos a second time, and augmented the field notes with more detailed notes generated in five-minute increments. I selected important sections of dialogue that were captured on video and transcribed and incorporated them into the detailed field notes.

Table 3.4

*Data Sources for the Case Study Teachers*

<b>Data Sources for the Case Study Teachers</b>	<b>Andy</b>	<b>Carla</b>	<b>Laurel</b>
Institute application	✓	✓	✓
Survey Responses (KSM, VNOS-C, VOSE)	✓	✓	✓
PD Institute Daily Reflections	✓	✓	✓
Pre Institute Video of Modeling Lessons	✓	✓	✓
Video of Institute Modeling Lessons	✓	✓	✓
Video of Classroom modeling Lesson	✓	✓	✓
Field notes from in-person observations	✓	✓	✓
Interview transcripts classroom observations	✓	✓	✓
Classroom Lesson follow-up interview transcripts	✓	✓	✓

The first round of data analysis began when I generated detailed memos (Birks, Chapman, & Francis, 2008) describing the progress of five participating teachers as they began to engage in MBT. Memos were used to document the decision making process throughout this research study as well as a tool for analyzing the data. The process of generating memos bridged the divide between the concrete data and the conceptual meaning that can be drawn from the data (Birks, et al., 2008). The memos recounted the

progress of each of these five teachers, from before the institute all the way to the time following their classroom enactment of a modeling lesson and were continually revised with additions gleaned from new data sources as they were obtained. Using a constant comparative method (Lincoln & Guba, 1985), the memos were analyzed and coded for instances of change in teacher growth as they engaged in some portion of the modeling cycle and defined as an enactment or a reflection according to the IMPG framework. In the constant comparative method, analysis begins with selection of a particularly interesting piece of data from one data source and compares it to another instance from the same set of data or from another set. These pieces of data are referred to as a unit of data and as such each unit of data should be both heuristic and interpretable on its own (Lincoln & Guba, 1985). The comparison process leads to the development of tentative categories at first, and then through subsequent rounds of comparison with new pieces of data, more structured and permanent categories are generated. The categories are concepts that the data indicate are important. Categories are chosen for their ability to cut across the data and include a variety of data points with common characteristics represented by the category. Above all, the categories should reflect the purpose of the research.

Once the categorization is completed, theories that attempt to explain the data can be generated and supported by the categories. While the categories describe the data, the theory building process involves making inferences from the data. This can be achieved by organizing the categories into a coherent framework such as a concept map. The arrangement of the categories into the map can then make the theory building process more thoughtful.

Once the extensive memos were written for each of the 5 teachers, comparisons between the progresses of each teacher were made and potential patterns within the data were identified. Through this process, I began to recognize the similarities and differences in the progress of my participants. I also began to see relationships between the factors identified in my guiding questions (knowledge of models, use of questioning, and beliefs about NOS) and the participants' growth in their abilities to implement model-based teaching. As new themes and patterns were identified within a memo, these themes or patterns were sought out in the other memos, often requiring the reanalysis of previously analyzed memos. It was during this stage of comparative analysis that I began to recognize a possible progression for teachers implementing model-based teaching.

Once an implementation progression began to emerge, I recognized that three of the five teachers were similar enough in their progress towards implementing model base teaching that I could select one and use it as a typical case (Patton, 2002) of this level of progression. A typical case is identified as the "average-like" case and can provide a baseline by which to evaluate less typical cases. The other two of the five teachers each demonstrated different levels of progression and were selected as critical cases. Critical cases are participants who exemplify the phenomenon in such a way that their description can make a dramatic statement about the phenomenon being studied. Based on the recognition that each narrative represented a different amount of progress towards successful implementation of model based teaching, cases were reorganized to demonstrate how each case was a representative of one of three different stages in this progression. Descriptions of each stage were developed using the data from each case.



The choice of cases to use can greatly impact the ability of the researcher to accurately represent the phenomenon and coherently describe the phenomenon in the form of a high quality qualitative report (Patton, 2002). High quality qualitative research is described as being a description of a worthy topic, having rich rigor, demonstrating sincerity, credibility and resonance, as well being an ethical study that provides significant contribution with meaningful coherence (Tracy, 2010). The description of these cases not only allows for an in-depth look at each type of case but connections between cases can be identified and used for establishing transferability of the research findings (Lincoln & Guba, 1985).

At this point, written narratives for each case were developed from the memos for these three teachers. For each narrative, I generated a visual map of each teacher's progress from pre-institute to post modeling lesson implementation. In accordance with the call from Clarke and Hollingsworth for each domain, reflection, and enaction of a growth network to be supported by empirical evidence, each case narrative was constructed using evidence from the extensive memos. The narratives focused on describing how the interactions between the teachers and students, the context of the classroom, and the curricular content of the lesson, were examples of enactions and reflections according to the IMPG framework. These narratives provide a rich, intensive, and holistic description of each case.

These five teachers, for whom extensive memos were generated, were a convenience sample (Patton, 2002), chosen for analysis because they represented the most complete data sets and the fact that they were observed implementing a modeling lesson in their own classrooms following the institute. A convenience sample is the least

desirable type of sample but still affords the opportunity to look for cases that warrant in-depth analysis. However, from within in this subset of teachers, I was able to identify three typical cases and two critical cases. This allowed me to purposefully select three cases for use in the cross case analysis.

Each of the three purposefully selected cases begins with a detailed description of the findings of each of the four instruments used to identify the teachers' knowledge of models (KSM), skills with facilitating classroom discourse through questioning (EQUIP), views and knowledge of the Nature of Science (VOSE & V-NOS-C), and ability to implement model based teaching (MBIPP). These descriptions provide a thorough background for each teacher with regards to salient aspects of their previous knowledge and skills prior to their classroom implementation. The descriptive profiles of each teacher's knowledge and skills are followed by the descriptive narratives that support the visual maps generated through the use of the IMPG framework.

### **Validity, Reliability, Generalizability, and Subjectivity**

In a quantitative approach to research, objectivity and universality are highly valued attributes of any research findings. These are translated into the statistical concepts of reliability and validity in an effort to establish generalizability (Auerbach & Silverstein, 2003). Qualitative research, due to its inherently contextualized nature, cannot adequately satisfy reliability and validity as the terms are defined by quantitative analysis. However, the qualitative approach has many rigorous qualities.

Reliability, in quantitative research is achieved when a particular instrument provides the same evidence repeatedly. In other words, the findings of one study can be repeated in a similar study with a similar population. Due to the highly contextualize

nature of qualitative research the term reliability, as defined in the quantitative paradigm, is irrelevant and ineffective at best. If the term reliability is reconstructed to mean quality then we can see quality in qualitative research embodied by understanding a phenomenon.

In this study, multiple sources of evidence were drawn on when establishing understanding of a given aspect of the participants' knowledge, skills, or practice. For example, when determining a participants understanding of the Nature of Science, two measurement instruments, classroom video, and transcripts of interviews were all used to determine a given participants understanding of the NOS. These various data sources served as triangulation points and supported the conclusions drawn about a participant's level of understanding. This pattern of triangulation was employed throughout this study.

Validity, in quantitative research, is defined as the ability of an instrument to measure exactly what it was intended to measure. For qualitative studies, Lincoln and Guba (1985) suggest a more useful term than validity for qualitative studies would be the term trustworthiness. Trustworthiness is the establishment of confidence in the findings (Lincoln & Guba, 1985). In this study, trustworthiness was established in a variety of ways. Through the use of a peer-reviewed analysis framework, the Interconnected Model of Teacher Professional Growth (IMPG)(Clarke & Hollingsworth, 2002), the use of a constant comparative method of data coding and analysis (Lincoln & Guba, 1985), and the periodic feedback on methods and interpretation of my findings provided by critical friends from the field of education, trustworthiness was established. For example, it was pointed out by a colleague that the instrument used to monitor and evaluate a participant's use of classroom questioning used language similar to the language used in

another assessment tool used in this study, the Learning Progression for Model Based Inquiry. Upon further investigation of language used by each instrument, I found that although the same words were being used, they were being employed in very different ways. This finding supported the distinctions between the instruments and is an example of how the findings of this study demonstrate trustworthiness.

Although validity cannot be guaranteed, several additional methods for asserting validity have been built in to the mixed method approach of this study. Fifteen teachers participated in this study. Complete data sets were obtained for five of the fifteen participants. Of these five participants, three were purposefully selected for the multiple case study. The purposeful sampling strategy that seeks maximum variation allows for greater application of the findings (Patton, 2002). The mixed method approach allows for the use of multiple sources of data and collection methods to confirm emerging findings thus effectively triangulating data and enabling plausible conclusions to be drawn (Maxwell, 2005; Merriam, 2002). Analysis of the quantitative data leading to focused qualitative data collection through in depth interviews provided a rich data set that makes it difficult to support a mistaken conclusion.

With regards to the quantitative requirement of generalizability, qualitative researchers suggest the use of the term transferability (Auerbach & Silverstein, 2003). Generalizability refers to the ability of research findings to be predictive of another group, different from those in the study. The term transferability embodies this idea but suggests that it is the abstract patterns rather than the specific content of those patterns that can accurately describe another set of participants (Auerbach & Silverstein, 2003).

Although reliability and validity are important to all types of research, their application to

qualitative research must be tempered by the inherent subjectivity and contextualized nature of qualitative research. For this study, the development of a possible performance progression that can be used as an interrogatory tool for future professional development satisfied the need for transferability in that it describes patterns of teacher growth that can be tested by future professional development.

Critics of qualitative research site the researchers subjectivity as the leading problem with the coding of data in a qualitative study describing the coding process as one that attempts to quantify what is strictly qualitative data. However this criticism can be overcome by clearly defining the categories that are developed. The impact of the researcher's subjectivity should be clearly explained and the progression leading from the data to the findings should be explicit.

The social constructivist perspective also recognizes that the researcher brings with him or her certain ideas and understandings to the research. This subjectivity is not suppressed but rather acknowledged as a key part of the interpretation of the data (Creswell, 2003). At the time this research was conducted, I was a classroom teacher within this state. Since I did not work directly with any of the teachers in the study group, nor did I hold any position of power over those teachers, the collegial relationship helped me to build rapport and provided access to the study population.

## CHAPTER 4

### FINDINGS

The New Framework describes the importance of engaging students in constructing models that explain phenomena, demonstrating how their models are consistent with their evidence, and identifying the limitations of their models (NRC, 2012). This process of developing and using models is identified as one of seven scientific practices that should be used in the science classroom. Developing and using models has also been identified by others as an important practice that guides the other practices and provides a coherent framework on which the other practices can be organized (Schwarz & Passmore, 2012). With this perspective, the generally accepted aspects of the Nature of Science (NOS) should closely align with the nature of modeling. Furthermore, these connections extend to the science classroom in meaningful ways and can be drawn upon to facilitate scientific literacy.

In this chapter, I will describe the findings of the first part of this research study. Part 1 of this chapter will describe the nested, quantitative analysis that examined the relationship between the participants' Knowledge of Scientific Models (KSM), understanding of the Nature of Science (NOS), their use of questioning to facilitate Model Based Teaching (MBT), and their implementation of MBT. I will begin with an

overview of all of the participants' collective views and understandings of these factors. I will conclude with a quantitative analysis of how these three factors, impact MBT.

### **Knowledge of Scientific Models and Modeling**

The 15 participants of the summer institute completed the Knowledge of Scientific Models (KSM) survey (Appendix A) before and immediately following the summer institute. The KSM survey has 8 open-ended questions that assess a respondent's knowledge of three dimensions of knowledge about models. These survey responses were the primary sources of data for identifying the participant's knowledge of models and modeling leading up to their implementation of modeling in the following school year. When relevant to items on the KSM survey, participants' statements about models and modeling on the daily reflections or other utterances in interviews and videos from the institute were used as triangulation points to support interpretations of responses to the KSM survey. A descriptive scoring rubric (Appendix B) was used to generate scores for each participant based on their responses to the KSM survey. A score of 1 indicated an incorrect or unformed understanding of KSM, a score of 2 indicated a developing understanding typical of most teachers, a score of 3 indicated a proficient understanding, and a score of 4 would indicate an informed, expert-like understanding of KSM.

While many researchers describe dimensions of modeling knowledge in several different ways, the dimensions used for this study emerged from the coding of responses from participants of this study. These dimensions are The Nature of Models (Dimension 1), Connections Between Scientific Models and the Nature of Science (Dimension 2), Connections between Scientific Models and Teaching (Dimension 3). While some

questions on the KSM survey are more likely to result in responses that fall into one of these dimensions, the open-ended response format allowed for any response to provide insights into any one of these three dimensions. For example, Questions 2 and 4 might elicit responses that are directly tied to connections between models and the NOS (Dimension 2), yet respondents may have provided details about how they understood models in their responses, which would inform their views, and understandings in Dimension 1. Likewise, Questions 6, 7, and 8 are closely aligned with Dimension 3 (Connections between Models and Teaching) but in several instances, were able to elicit ideas about how models are connected to the NOS, (Dimension 2). Participants' scores for the KSM survey are listed in Table 4.1.

Chi square analysis was used to analyze whether there was a significant similarity between the dimensions of knowledge of models and modeling as described by the KSM survey rubric. No significant association was found thus indicating that each dimension was different enough from the others to say that there are distinct differences in the dimensions.



Table 4.1

*Participants' Knowledge of Models and Modeling*

Participants	The Nature of Models	Connections Between Scientific Models and the Nature of Science	Connections between Scientific Models and Teaching	Averaged Score
Rachael	2	2	3	2.3
Christina	2	3	3	2.7
Henry	3	2	2	2.3
Maggie	3	2	3	2.7
Justine	3	2	3	2.7
Alan	3	3	2	2.7
Sarah	2	2	2	2.0
<b>Andy</b>	2	3	3	2.7
Denise	2	2	3	2.3
Debra	2	2	2	2.0
Jeanie	3	3	3	3.0
<b>Laurel</b>	2	2	3	2.3
Barry	3	3	3	3.0
Patti	3	2	3	2.7
<b>Carla</b>	2	2	3	2.3

The analysis of the KSM surveys and other associated data sources indicated that, of these 15 teachers, 12 held developing knowledge levels of models and modeling across the three domains identified by the KSM prior to attending the summer institute. Three participants held uninformed levels of knowledge of modeling prior to the institute. As a result of participating in the summer institute, all 15 teachers improved their knowledge of models and modeling (Table 4.2). The three participants with uninformed views prior

to the institute were able to make large gains. Sarah, Debra and Carla each moved from uniformed levels of knowledge of models to developing levels of knowledge. Jeanie and Barry, two teachers who came into the institute with developing levels of knowledge were able to improve their level of knowledge to a proficient level. Although the remaining ten teachers did improve their understanding of models, the improvement of these teachers were only within the level of developing modeling knowledge and thus was not measurably large enough to change their overall level of knowledge of models.

Table 4.2

*Knowledge of Scientific Models Diagnostic Assessment*

<b>Participant</b>	<b>Before</b>	<b>After</b>	<b>Change</b>
Rachael	2.0	2.3	0.3
Christina	2.0	2.7	0.7
Henry	2.0	2.3	0.3
Maggie	2.0	2.7	0.7
Justine	2.3	2.7	0.4
Alan	2.0	2.7	0.7
Sarah	1.0	2.0	1.0
<b>Andy</b>	<b>2.0</b>	<b>2.3</b>	<b>0.3</b>
Denise	2.0	2.3	0.3
Debra	1.7	2.3	0.6
Jeanie	2.3	3.0	0.7
<b>Laurel</b>	<b>2.0</b>	<b>2.3</b>	<b>0.3</b>
Barry	2.0	3.0	1.0
Patti	2.0	2.7	0.7
<b>Carla</b>	<b>n/a</b>	<b>2.3</b>	<b>n/a</b>
<b>Mean</b>	<b>1.9</b>	<b>2.5</b>	<b>0.6</b>

All teachers improved their KSM scores as a result of participating in the summer institute (mean change = .59, median change = .65, Std. Deviation = .24). The data above were analyzed using a paired-Sample T-test which showed that there was a significant difference in the scores for the pre-institute KSM (M=1.9, SD=.294) and the post-institute KSM (M=2.55, SD=.298);  $t(13)=-32.01$ ,  $p=.000$ . While other factors may have been involved, since the institute represented five, 8-hour days focused on modeling, it is safe to interpret these findings as directly resulting from the institute. In the following, section I will provide a more detailed description of each dimension and the associated findings.

### **Dimension One: Knowledge of the Nature of Scientific Models**

Teacher's descriptions of models fell into general categories including simulations, representations, or demonstrations that were used when the scale or size of something made it inaccessible to study. For example, one teacher described a model as "a representation of some natural phenomenon that is too large or too small to study directly". The most common examples provided by the teachers included models of the atom ( $n=5$ ), solar system models ( $n=4$ ), and replicas of a cell ( $n=3$ ). Only 1 of the 15 teachers defined scientific models with some connection to the discipline of science. In his response, Barry defined a model as, "A simulation of a real system using the empirical data which has been collected. It is used to test the validity of the theory." An expert-like definition would include describing models in terms of their relationship to a target and as such are purposefully constructed to be predictive, explanatory, and/or descriptive. Multiple models may exist for the same phenomena and depend on the purpose for which the model is to be used. In his response, Barry mentions a system

thinking definition as well as referencing empirical data and validating a theory.

Including ideas such as these in defining models indicates a more informed understanding, approaching that of an expert like description.

Teachers included a wide variety of characteristics of quality models in their responses to Question 3 on the KSM. Prior to the institute there was not as much similarity in responses between participants as there was after the institute. For example, only five participants mentioned accuracy as an important characteristic of models prior to the institute. On the post institute KSM, eight respondents included accuracy in their description. Similarly, only one participant mentioned the empirical nature of models prior to the institute, yet after the institute five participants listed this as an important characteristic of models. Another interesting finding was that prior to the institute, only one participant mentioned that models should be predictive. After the institute, five participants included this in their description of the characteristics of high quality models.

### **Dimension Two: Connecting Models to the Nature of Science**

In describing how scientists use models prior to the institute, teachers' responses focused on using models for explaining complex data or phenomena (n =8). While other uses such as seeing patterns, constructing theories, and making predictions were mentioned, they were mentioned by fewer teachers and in most cases each was mentioned by only one teacher. The only uses mentioned by more than one teacher were explanatory uses of models (n = 8), the ability to manipulate a model instead of the real thing (n = 2), and as replicas of objects that were too big or too small to directly see (n = 2). After the institute, teachers were much more likely to include predicting (n =5), seeing

the unseen (n = 5), and representing empirical data in order to make patterns visible (n = 5). Some teachers mentioned sense making and connected the use of models to an iterative process (n = 2).

### **Dimension Three: Connecting Models with Teaching**

The primary source of data about how the participants viewed the connection between models and teaching came from the pre-institute KSM survey. Questions 5, 7, and 8 focused on how participants used models in their teaching, how student used models in their classroom, and what participants thought about how students viewed models. These questions were not asked on the post institute KSM survey. These questions were only asked prior to the institute since there would have been no time to change their classroom practice before the KSM post survey.

In response to Question 5, which asked, “How do you use models in your teaching?”, 14 of the 15 teachers stated they used models in their classroom teaching (the one that responded no was a first year teacher and had not had her own classroom yet). The teachers referred to a variety of ways that they used models in their classrooms. The most common responses included using models to introduce content (n = 3), demonstrate a concept (n = 3), or help students understand a concept (n = 6). Teachers also described how they use analogical models to “make the abstract concrete” (n = 3), as one teacher wrote. This was also described as “connecting the known to the unknown”. Four teachers also described how they engaged students in making models of various things such as collected data, the cell, the solar system, or DNA. In response to Question 8, which asked, “In your classroom, do students produce their own models? If so, what do you do

with them?”, 10 teachers said they engage students in building models, 2 teachers said sometimes, and 3 teachers said not at all. All three teachers who said no cited not having enough time as the main reason. These three teachers were not part of the multiple case study. One of the three teachers described the lack of “scholastic confidence” held by students and another stated that the “attention span [of students] is not there”. In response to question 7, the most common descriptions of how students understand the word model included as representation of something else (n = 5), a simplified replica or a physical model (n = 6), or they weren’t sure (n = 4). Those that weren’t sure included comments like, “I never ask them”, or “I never explicitly talk about models”.

Shifting understandings and views of modeling pedagogy were evident in the reflections teachers wrote during the institute. On day two of the institute, the responses to the daily reflection questions that asked about the participants changing views of models were overwhelmingly positive. Justine, a high school biology teacher stated, “It [scientific modeling] allows us to be able to work *with* our students instead of teaching *at* [emphasis in the original] them. I don’t think students will become as bored and uninterested using this strategy.” Another high school biology teacher, Maggie said, “As a teacher it will enable me to get my students more involved and actively engaged (meaningfully). Students will leave with a better understanding and will be able to fully explain process like mitosis without just memorizing but through application of knowledge.” These statements are representative of the responses of almost all of the 15 teachers. While most teachers came away from the modeling activities with a greater understanding of and appreciation for scientific models and modeling, some were hesitant. These hesitant teachers were mostly concerned with time required to plan the

modeling lessons but also the time in the classroom to implement the lessons. They also voiced concerns that modeling was only applicable to certain content topics.

### **Understanding the Nature of Science**

Participants in this study completed an abbreviated version of the Views of the Nature of Science version C (VNOS-C) survey (Lederman et al., 2002). The questions from the VNOS-C used in this study were focused on ascertaining participants understanding and intentions to teach about the creative and tentative aspects of NOS. These aspects of NOS were selected based on their close association with many aspects of scientific modeling.

Participants also completed the Views of the Nature of Science and Education (VOSE) survey (Chen, 2006). The VOSE asks Likert-type questions about a variety of NOS topics associated with widely accepted aspects of the NOS important in science education. Average scores for this study's participants' views of the NOS as determined by the VOSE are presented in Table 4.3. Scores ranged from 1 to 5, with 5 being very informed and 1 being uninformed about an aspect of the NOS.

The quantitative results from the VOSE survey were used in the analysis for the quantitative part of this study. The second part of the study, which was a qualitative multiple case study, used both the VOSE scores as well as the open-ended responses from the VNOS-C. Using both sets of data for the qualitative analysis afforded more reliability when interpreting the data.

Table 4.3

*Teachers' Average VOSE Scores for NOS Aspects*

	Understanding	Important to Teach
Creativity	3.7	n/a
Tentative	3.7	4.3
Theory Law Relationship	2.4	4.1
Inaccuracy of TSM	2.1	2.1

In general, participants held transitional views of the imaginative and creative aspects of NOS. This is indicated by the average score of 3.7 which falls below the 70% congruence mark suggested by the scoring of the views of the NOS used by Herman et al. (2013). It is worth noting that, while this is below the 70% line, it is at the upper extent of the transitional categorization. The majority of participants, with the exception of four participants, held transitional views of the relationship between Scientific Theories and Laws as indicated by the score of 2.4 in table 4.3. Again, it is worth noting that this average score is just barely above the 70% incongruence line set at 2.2 thus indicating that the average view is only barely transitional. In spite of their transitional understanding, most participants felt it was very important to teach about these tenets and the relationship between them in spite of not recognizing their own misconceptions about them as indicated by the score of 4.1 for the importance to teach this aspect of the NOS as seen in table 4.3. With the exception of one participant, participants believed that “The Scientific Method” was the way science was done and that it was important to teach it to students. The scores of 2.1 in Table 5 indicate that they did not agree with the inaccuracy of TSM. (These low scores are examples of teachers supporting an inaccurate view of NOS and were inverted to be low numbers on the scale.)



## Creativity and Imagination

Many teachers agreed that in science, there was a place for creativity. Generally, teachers responded similarly to Carla when she stated, "...the place where [scientists] use their imagination and creativity would be in planning and designing." Some teachers went one step further like Laurel when she stated, "...data can be interpreted differently and that may require some imagination." Yet, most stated that the place for creativity was in the design of experiments and not in the interpretation of data or the analysis of results. Justine, a HS biology teacher, stated, "Scientists will use their prior knowledge and every decision that a person makes is going to have some level of intuition attached to it. However, the job of the scientist is to solely rely on data and learn how to put intuition and prior beliefs aside." Barry, one of four teachers who held an informed view of science, stated, "In almost every step the imagination and creativity have to be there--from coming up with what to study, designing the test, to forming a conclusion. Data collection is not as open to creativity. This has to be quantitative and not open to imagination." So, generally, teachers were appreciative of imagination but reserved it for only specific parts of the scientific process, a common finding in other studies on teachers' views of the (Lederman, 1999; Schwartz et al., 2004).

**Tentativeness.** Results from both surveys indicated that teachers supported the tentative nature of science and believed that they should teach their students about how science is constantly changing. Carla stated, "Science is changing rapidly because of technology and what we believe today may be obsolete tomorrow." Jeanie stated, "nothing in science is ever really complete...there is always room for further discovery!"

## Theory and Law

Of the 15 teachers, few references to scientific laws were included in the open ended responses of the VNOS-C. However, responses to the VOSE questionnaire and the questions specifically targeting the relationship between laws and theories indicated that only four teachers held a correct understanding of the relationship between theory and law in science. Barry, the most informed participant concerning NOS, stated, “Theories are just ideas of how things work but have an abundance of data to support the theory. By the time one gets to the theory stage [change] is difficult--but it can happen.” Denise had an informed view of this relationship and stated, “Scientific theories can be challenged and changed through substantial observations and experimentation.”

Responses to Question 7 from the VOSE indicate that most teachers were uninformed about the relationship between these two constructs. As seen in table 4.3, the average VOSE score for items associated with Theories and Laws was 2.4, indicating a naïve understanding of this aspect of NOS. This score means that most teachers agreed with incorrect views of the relationship between Theories and Laws. Teachers agreed with statements that theories had less evidence to support them than laws and that there was a hierarchal relationship to theories and laws (that theories could become laws). The best example of this view is demonstrated in Carla’s response on the VNOS-C, “Theories are simply used to explain certain observed phenomena that has been proven to some degree and is a conjecture or educated guess. The theory of man evolving from tadpoles and the theory of humans evolving from monkeys are very debatable issues. Each theory has enough evidence to give weight, but neither has been proven.” In a similar way Sarah stated, “theories are just that, theories, and nothing about them is definite, information is

gathered and a theory is created until further and more definite information can [be] proven and a law is developed theories [that] have a lot of information to back them up so we have to use the theories like they are all we have". As we will see later in part 2 of this study, not understanding the structures of scientific knowledge makes understanding and implementing the modeling process more difficult.

### **The Scientific Method**

Fourteen of the fifteen participants in this study indicated that they adhered to a definition of science that was embodied by "The Scientific Method." Typical of most participants, Andy explains how, "Science is the application of the scientific method to discover new knowledge". Alan, further explains TSM by saying science "almost always begins with an observation coupled with curiosity on the part of the scientist to want to know "why or how does that happen?" It proceeds with experimentation in an attempt to arrive at answers to the question...the data from the experimentation is objectively analyzed to arrive at a conclusion about the issue. Of course, this conclusion might also lead to further experimentation and/or the investigation of a whole new problem to pursue." While this statement, approaches seeing science as iterative, it is only iterative in the sense of repeating the steps of TSM. Maggie states, "Science is different from other disciplines because it consists of a systematic process scientists use to conduct research. Everything that relates to science must be tested continuously to provide concrete evidence." These are just a few examples of how teachers' adherence to a universal scientific method appropriate further complicates their understanding of science. Part 2 of this study will show how possessing this view of TSM complicates the process and impedes the ability of these teachers to implement modeling in the classroom.

## Use of Questioning to Facilitate Modeling Discourse

One primary focus for the summer professional development institute was the use of questioning to support MBT. During the summer professional development institute, teachers were given an opportunity to practice teaching a modeling lesson that they had co-designed with other participants. These lessons were video recorded and the recordings served as the primary data source for evaluating their use of questioning. Several strategies were presented and demonstrated to the teachers participating in the institute. These strategies included a brief overview of Socratic questioning and a collection of conversational strategies known as “discourse moves”. The discourse moves discussed included the reflective toss (Minstrell & van Zee, 2003), pressing, re-voicing, and encouraging peer-to-peer talk. Lead teachers were also thoughtful about demonstrating these moves when leading the other activities of the PD institute.

During the institute, teachers were assigned to small, content specific groups in which they explored a content topic through a model-based approach. They were then asked to use this experience to develop a model-based lesson that would be enacted during the last two days of the institute. In planning these lessons, teachers were encouraged to include some or all of the questioning strategies that had been introduced to them and to practice using those strategies during the enactment of their lessons.

Table 4.4

*Use of Questioning During Institute Instruction*

Group 1		Group 2	
Carla*	3	Christina*	2
		Sarah*	2
		Jeannie	4
Group 3		Group 4	
Alan	2	Laurel*	3
Barry	3	Justine	3
Group 5		Group 6	
Henry	2	Debra	2
Andy*	2	Rachael	2
Denise	3	Maggie	3
		Patti	2

\* indicates classroom observation was completed and used in scoring

On day four and five of the institute, participants enacted their small group developed modeling lessons while the other participants acted as students. These modeling lessons were recorded and analyzed using the EQUIP discourse rubric (Marshall, et al., 2010). The scores for each group and each participant are shown in Table 4.4. Each lesson was followed by a debriefing session in which participants leading the lesson were asked to describe what went well, what was difficult, and what they think their next steps might be in their lesson development. Since the lessons were led by groups of teachers, EQUIP scores were a bit more difficult to assign to one participant. Decisions about each participant's summative score had to be made based on their contributions to the implementation of the lesson. In most cases, scores were

similar. However, in some groups participants stood out. For example in Group 2, Jeanne was much more focused on asking questions that required “students” to explain their thinking. She often asked follow up questions that probed the idea being shared. As she was doing so, her co-teachers, Sarah and Christina, were typically asking recall questions during the session. In general, most participants’ use of questioning was scored as “developing” (N=8) while a smaller portion (N=6) scored in the “proficient” range. Only one teacher, Jeannie, was scored as “exemplary”. Carla, due to her selection of an earth science topic, was the only participant who implemented her lesson on her own.

### **MBT Implementation**

In order to determine a score for each participant’s implementation of model based teaching practice, the small group modeling lessons enacted by participants were recorded and analyzed using the Teacher’s Performance Progression for Model Based Inquiry (Thompson, et al., 2009) (Appendix D). This instrument was used to identify a numerical score for each participant in the four categories of the progression. Scores in each dimension were then averaged to produce an overall score. An overall score of 1 indicated an unsophisticated level of implementation, a score of 2 indicated a developing level of sophistication; a score of 3 indicated proficient level of sophistication, and a score of 4 indicated a sophisticated, expert level of implementation of model-based teaching.

Five of the fifteen teachers who participated in this study were observed implementing a model-based lesson in their own classroom during the school year following the institute. For these teachers, implementation scores based on analysis of

video recordings of classroom observations were higher than their implementation scores for the institute lessons. Table 4.5 below shows the MBT implementation score for each participant. The scores are organized according to the content area group they were a part of at the summer institute. Teachers whose scores resulted from classroom observations are indicated with an asterisk. The Performance Progression for Model Based Inquiry (PPMBI) was used as a rubric for scoring each participant's implementation of MBT. The PPMBI is subdivided into four categories associated with implementation. Below I will describe my findings according to each category of the progression.

Table 4.5

*Implementation of Model-Based Teaching*

Group 1		Group 2	
Carla*	2	Christina*	2
		Sarah*	2
		Jeannie	3
Group 3		Group 4	
Alan	2	Laurel*	3
Barry	2	Justine	3
Group 5		Group 6	
Henry	2	Debra	2
Andy*	2	Rachael	2
Denise	3	Maggie	2
		Patti	2

\* scores based on classroom observation

## Selecting Big Ideas and Treating them as Models

During the institute, teachers spent time in content specific teams to experience modeling lessons as learners and to develop their own modeling lessons. Instructors presented modeling lessons that focused on understanding the causal mechanisms underlying particular phenomenon. For example, in the biology content group, teachers explored the process of sexual recombination as the underlying mechanism of inheritance. During the development of the practice modeling lessons, instructors encouraged participants to maintain focus on “big ideas” as they developed their lessons. Despite these efforts, participants were generally found to be at a developing level of sophistication when selecting big ideas and treating them as models. Topics selected during the institute were generally better linked to a big idea than those topics selected for classroom implementation. For example, Carla developed an activity at the summer institute that engaged participants in generating a model that would explain the phases of the Moon. This lesson linked an unobservable phenomenon, the orbit of the Moon around the Earth, to an observable phenomenon, the changing view of the Moon from the surface of the Earth. During her classroom lesson using models, students were engaged in generating descriptive models of the geological history of the Earth. These models did not attempt to explain any big idea related Earth’s history other than the idea that Earth has changed over time. In other words, no causal mechanism was included in the discussion or in the models themselves. This “fall off” of focus on big ideas was evident in 4 of the 5 classroom observations conducted after the summer institute.



## **Attending to Student Ideas**

During the institute-developed lessons, most participants were actively practicing the questioning techniques discussed during the institute. The questioning was primarily focused on eliciting student ideas and questions. Analysis indicated that generally, participants were proficient at eliciting student ideas but struggled to either build on those ideas throughout the lesson or incorporate them into the directional decisions during the course of the lesson. For example, Laurel’s group was visibly mindful of using good questioning strategies but missed several opportunities to push participants thinking about the models being generated in their lesson. Questions were mostly pre-determined and improvisational questioning was more limited.

## **Choosing Activity and Framing Intellectual Work**

Participants enacted lessons at the summer institute that engaged the other participants in discovering a science concept for themselves through the generation of models. None of the institute developed modeling lessons achieved a proficient level of implementation according to the MBI learning progression. This is not surprising considering that these lessons were most teachers’ first attempts at developing and implementing a modeling lesson. This category attempts to evaluate a teachers’ ability to help learners understand models and theories as the “currency of scientific knowledge” (Thompson, et al., 2009). Thompson et al. (2009) describe the difficulty of this in light of the common curricular materials that teachers have available. These curricular materials are often composed of activities that engaged learners in confirming known scientific ideas. Thus, implementing activities that engage students in predicting and changing

ideas as a lesson progresses is quite difficult for most teachers. When considering the finding that this group of teachers places a high level of importance on the “The Scientific Method”, it is not surprising that this category of the MBI progression was the most difficult for them to demonstrate a sophisticated level of implementation.

### **Pressing for Explanation**

Since the act of pressing students through questioning was a focus of the activities at the summer institute it is not surprising that participants were generally proficient in this category. The average score for a participant in this category was a 3. In response to learner ideas, participants often used follow up questions like, “What evidence do you have for that claim?” or, “Why do you think that?” These types of follow up questions were both demonstrated and discussed by the institute instructors at the summer institute.

### **Summary**

Pearson Chi square analysis was used to identify if there were any statistically significant associations between the independent variables (knowledge of models, knowledge of NOS, use of questioning) and the dependent variable (implementation of MBT). The findings of this analysis shown indicated that while there were no significant associations found between knowledge of models and implementation, no statistically significant associations between understanding of NOS and implementation, there were statistically significant associations between the use of questioning and the implementation of MBT,  $\chi^2(2, N=14)=6.65, p<.036$ .

In general, this population of teachers (N=15) were uniformed about the nature of Scientific Models and modeling, developing their ability to use questioning, and

transitional in their understanding of the Nature of Science. A statistically significant relationship was identified between the teachers' use of questioning and their implementation of MBT. This relationship will be further supported in the qualitative analysis in part two of this study and prove to be a significant finding of this study overall.

## CHAPTER 5

### CASE STUDIES

While the total number of participants involved in this study was 15, complete sets of data spanning the time from pre institute surveys to classroom modeling lesson observations were obtained for only five participants. Extensive memos were generated for each of these five participants. After an initial and extensive analysis of these memos, it was noted that three participants were similar enough that a “typical” case was selected that represented all three participants. The two remaining participants were unique examples and were selected as “critical” cases. This chapter provides the in-depth cases associated with these three participants.

A wide variety of data sources were used for developing the cases. Prior to the summer institute, teachers submitted lesson plans and videos of themselves teaching. They also completed two surveys focused on their knowledge of the nature of science, and one additional survey focused on their knowledge of scientific models and scientific modeling. During the institute, daily reflections were completed by each teacher and all teacher created modeling lessons were collected for analysis. Following the institute, participants again completed a survey focused on their knowledge of scientific models. Five teachers were observed enacting model based lessons, either in person or via video recording. Semi-structured interviews were conducted with teachers before and after the in class modeling lessons were conducted.

Clarke and Hollingsworth(2002) discuss the ability of the Interconnected Model of Teacher Professional Growth (IMPG) to be used as an analytical tool for categorizing teacher change data. The IMPG describes teacher professional growth in terms of four interconnected domains of change. These domains include the External Domain, the Personal Domain, the Domain of Practice, and the Domain of Consequence. According to the model, professional growth can be measured as change in one of these domains. These changes are connected through the mediating process of “enactions” and “reflections”. An enaction is the translation of a belief or pedagogical model into practice. A reflection is a persistent or careful consideration of a belief, practice, or otherwise salient outcome. Series of reflections and/or enactions are classified as either change sequences or growth networks. Change sequences are progressions of 2 or 3 enactions or reflections while a growth network is characterized by more than three reflections or enactions (Justi & Van Driel, 2006).

Data analysis for each case began by identifying the teachers’ modeling implementations (enactions) or their reflections on their use of model-based pedagogy (reflections). A visual map of each teacher’s progress from pre-institute to post lesson implementation was generated based on their identified enactments and reflections. In accordance with the call from Clarke and Hollingsworth for each domain, reflection, and enaction of a growth network to be supported by empirical evidence, a case narrative was constructed to accompany each teacher’s diagrammatic map. These narratives provide a rich, intensive, and holistic description of the context, reflections, and enactions of each case.

Each of the following cases begins with an examination of the participants profile with regard to the three factors identified in the guiding research questions. These descriptive profiles provide a rich background on each participant that informs the in-depth case narrative generated through the use of the IMPG framework, which follows each profile.

### The Case of Andy

Andy has been teaching high school physics and chemistry for 8 years. He teaches at a large southeastern American high school. His school is on a block schedule so he teaches three 90-minute class periods each day. There are approximately 20 students in each of his classes. On his application for the summer PD institute, Andy indicated that he usually attends two “classes” each summer that focus on professional development.

Table 5.1

#### *Andy’s KSM Questionnaire Scores*

	Knowledge of the Nature of Models	Connecting Models to the Nature of Science	Connecting Models with Teaching	Overall Score
Pre Institute	2	2	2	2
Post Institute	2	2	3	2.3

#### **Andy’s Knowledge of Scientific Models**

Analysis of Andy’s responses to the KSM survey administered prior to the summer institute indicated he possessed a developing understanding of models. The categorization of a developing understanding of modeling indicated that Andy has a

typical knowledge level of models, similar to findings of the body of research focused on pre- and in-service teachers' knowledge of models described in chapter 2. In each of the three Dimensions of scientific modeling characterized by the KSM scoring rubric, Andy scored a 2, indicating a developing understanding within each dimension. The KSM survey was administered a second time, at the end of the summer PD institute. Although Andy's scores in Dimensions 2 and 3, Connecting models with the Nature of Science, and Connecting Models with teaching, rose from developing to proficient, his average score remained at the developing level.

**Dimension one: Knowledge of the nature of scientific models.** On the pre-institute Knowledge of Scientific Models (KSM) survey, Andy grounded his description of a scientific model in its ability to “accurately convey a topic”. He asserted that scientists use models to “describe concepts based on what is known or believed” and that he uses models to “demonstrate a microscopic concept [such as] the concept of the atom, isotope, ion, or molecule”. Andy identified scientific models as explanatory tools with a purpose primarily focused on teaching, in which they were “used for conceptual understanding” by students. Andy's understanding of scientific models also included the recognition that scientific models are both empirical and tentative. In a response to a question about how scientists use models Andy stated, “Models are used to describe concepts based on what is known or believed. Therefore, a model must conform to these. However, in its conformity, it may reveal components of the truth that have not been measured or otherwise tested and therefore leading research in directions to confirm or reject these theories”. This statement indicates how Andy understands how models are

developed based on experimental information and can then be modified or discarded based on new findings.

In terms of Dimension 1 of the KSM survey rubric, the Nature of Scientific Models, Andy's pre-institute KSM survey responses indicated that he had a developing KSM prior to attending the summer institute and was given a score of 2 for Dimension 1. Following the summer institute, Andy's responses to the post institute KSM survey did not indicate change in his understanding of the nature of scientific models. He continued to describe models in terms of their ability to "accurately and clearly illustrate scientific concepts". However, on one of the daily reflections, Andy stated that he was looking forward to using modeling as "an outcome for scientific inquiry" which indicated that Andy had recognized new purposes for scientific models. Although, this statement indicated a small change in his understanding of the purpose of models, his understanding of the Nature of models was still characterized as developing and scored as a level 2 by the KSM survey rubric.

**Dimension two: Connecting models to the nature of science.** In a statement on his KSM questionnaire prior to the institute, Andy described the empirical and tentative nature of scientific models. Andy suggested that models can "guide investigations when they illuminate a yet undiscovered truth" indicating he understands that models are testable constructs and may or may not be accurate representations of the real world until they have been vetted through experimentation. Andy's statement about the direction of the experimentation being guided by the model indicated that he understood how models can be investigative tools and that he recognized that models are based on evidence.

However, he also described how models enable the discovery of "the truth" and in



another response described models as the “rational process of discovery” which indicated a narrow view of the connections between models and the Nature of Science and the Nature of Science more generally.

After participating in the summer institute, Andy showed a gain in his knowledge of models based on his post institute KSM survey responses and his daily reflections from the institute. Andy’s improvements in Dimension 2 are demonstrated by his comments on his daily reflections during the institute when he stated on day 2 that he had gained a “...greater understanding of the difficulty in describing the scientific process”. Based on his strong adherence to the universal “scientific method” prior to attending the institute, this statement indicates that Andy is beginning to see how the processes of science are not wholly contained in a “universal scientific method”. In a response to the post institute KSM, Andy stated that scientist’s use their experimental information to construct a model. AS new information becomes available it is compared to the model and either supports or rejects the model. If the model is rejected, then it has to be adjusted”. These statements suggest that his experiences at the institute are creating a cognitive dissonance in his views about the processes of science and as such were an opportunity for him to grow in his understanding about how models play a role in the processes of science. To a certain degree, his appreciation of “the scientific method” is being challenged and he is working towards assimilating this new understanding into his view of science. These statements also indicate a small improvement in his knowledge of the connections between scientific models and the NOS after the summer institute. Prior to the institute, Andy’s score in this Dimension was a 2. After the institute, his score for

this dimension remained a 3, indicating a developing understanding of how models are connected to the Nature of Science.

**Dimension three: Connecting models with teaching.** Prior to attending the summer institute, Andy described models as tools for “describing a concept based on what is already known”. After attending the professional development institute, Andy understood that scientific models and teaching models were similar but different. He articulated how teaching models and scientific models are both intended to be used for conceptual understanding but that teaching models may be simplified versions in order to “not confuse or overwhelm” students. He also recognized that students probably had little experience with scientific models and as a result, thought of models as physical replicas. He described how he used scientific models in his own classroom, prior to the institute, to engage students in building “conceptual understanding” and used analogical models during lab activities. This was done through students building models of “molecular architecture and reaction models”. These findings indicated that Andy’s understanding of the connections between models and teaching science was proficient, earning a score of 3 for Dimension 3 on the KSM survey rubric. Movement in this level of KSM was not indicated for Andy following the PD institute. The next level of proficiency would require Andy to be using models to engage students in understanding underlying, causal mechanisms of phenomenon. His post institute classroom-modeling lesson did not indicate this was part of his usage of models. Nor was he engaging students in a process of scientific modeling, which is also an indicator of the next level of proficiency.

## Andy's Knowledge of the Nature of Science

In order to determine each participant's level of knowledge of the NOS, I aligned and compared responses to two instruments aimed at determining a respondent's level of understanding of the NOS, the VOSE and the VNOS-C. An alignment chart was generated for each participant and examples of these are contained in Appendix E. I will provide a summary table of each case study teacher's responses to the VOSE here, as in Table 5.2 for Andy.

Table 5.2

### *Andy's VOSE Scores*

Aspect of the NOS	Aspect Understanding Score	Importance of Teaching Aspect Score
Creativity and Imagination	4	-
Tentativeness	4	4
Theories and Laws	4	4
Inaccuracy of TSM	2.3	2
Average	3.6	
Level of Knowledge	Transitional	

Prior to the summer institute, Andy possessed a transitional understanding of the NOS. During the institute, Andy wrestled with his understanding of the nature of science as indicated by his comments about his difficulty in describing the scientific process. A person with an informed understanding can express consistent, non-contradictory views across multiple aspects of NOS. Andy's statements on the NOS related surveys indicate that he understands the major tenets of scientific knowledge and how creativity and

imagination are integral aspects of NOS. However, his understanding of the process of science is limited by his strict adherence to TSM, thus the transitional designation.

**Creativity and imagination.** Andy's survey results indicate his views of the imaginative aspects of NOS are congruent with the accepted view of this aspect of NOS. A person with an informed view of NOS recognizes that creativity innervates all parts of the scientific process. Using words like "inventiveness" and "resourcefulness" are good indicators of an informed view of this aspect of NOS. In responding to questions focused on this aspect he stated,

Interpretations of the experimentation are left to scientists' imagination as to how these results support or reject these positions/thoughts. Imagination and creativity are most effective in the design of an investigation. With appropriate background support and collegial concurrence a creative data collection method [can] be implemented. After data collection, care must be taken not to expand its interpretation beyond what the findings support, without so noting. Imagination and creativity are essential to the scientist. Scientists must draw on their background knowledge, new evidence, and recognition of unique phenomenon and how these might be associated in nature. Scientists must use their imagination and creativity to logically and accurately make the connections.

Andy views creativity and imagination as an integral part of many steps in the work of scientists. He also understands that the peer review process must temper creativity when he warns of the possible misuse of creativity, indicating a more sophisticated understanding of the processes of science. In his response, Andy correctly discussed the purpose of data as being to "support or reject" versus using the terms "prove or disprove".

**Tentativeness.** The tentative aspect of NOS involves understanding that scientific knowledge can change over time. This change can occur in different ways. Change can be revolutionary, occurring very quickly, evolutionary, changing incrementally over time,

or accumulative, thus simply adding new knowledge to the existing body of scientific knowledge. An informed view of the tentative NOS will recognize these aspects of NOS. Andy's understanding of the tentative NOS is similarly well informed to that of his views of the creative aspects of NOS. He states:

Scientific theories are explanations of natural events. Modern scientific theories represent facts as we presently know them. As our understanding of these events change then the theories are updated with new information.

In his discussion of scientific theories, we find his view of the tentative aspect of NOS as being that of a gradual, evolutionary perspective. Although his first sentence in the above quote indicates an informed view of the tentative nature of science, his second sentence then refers to theories as "facts". Upon carefully considering this statement, Andy seems to suggest that Scientific Theories are representations of how we understand the "facts". His use of the term "updated" indicates that he recognizes the ways scientific knowledge evolves incrementally. In his response to a related question on the VOSE (question 4 - methods of change in scientific knowledge), he indicates that he also understands how scientific knowledge can change abruptly based on new discoveries and accumulate over time. These findings indicate that, beyond his written response on the VNOS-C, that Andy is in fact proficient in his understanding of the tentative NOS.

**Theory and law.** An informed view of the differences and relationship between Scientific Theories and Laws requires recognition that these are in fact different entities. Theories are non-observable explanatory accounts of natural phenomena while Laws attempt to describe the patterns and/or relationships among those events. Both constructs are tentative, neither being more or less capable in their usefulness as predictive tools. A typical misunderstanding is to consider the two hierarchical. In other words, a Theory is somehow less than a Law and with further evidence, can turn into a Law. In his responses

to the survey questions probing his understanding of the relationship between Scientific Theories and Laws, Andy understands that Scientific Theories can be discovered or invented. He has a similar view of the nature of Scientific Laws, indicating he sees both as being mostly discovered but is not opposed to them being invented. Andy has an informed view of the relationship between Scientific Theories and Laws and strongly agrees that they, along with the relationship between them, should be taught to students.

**The scientific method.** Despite his apparent proficient understanding of many aspects of the Nature of Science, Andy adheres to a strict interpretation of the process of science as being embodied by TSM. He states, “Science [is] the application of the scientific method to discover new knowledge and a lesser extent to the applications [of] related practical application of technology”. In addition to this statement, his responses to VOSE questions 9 and 10, focused on the relative importance and role of TSM, indicate he supports this view of science and that it should be taught to students.

### **Andy’s Implementation of Model-Based Teaching**

Andy’s ability to implement Model-based teaching (MBT) was determined through the analysis of two data sources, his enactment of a model-based lesson at the summer institute and an additional video-recorded classroom lesson enacted in the semester following the summer institute. Analysis was done using the Performance Progression for Model Based Inquiry (Thompson, et al., 2009). The analysis of Andy’s modeling lessons led to his implementation being assigned a score of 2, indicating a developing level of model-based teaching. This means that while Andy is demonstrating some use of models and modeling in his instruction, he still has multiple avenues for improvement.

In the following section, I have broken down the analysis of Andy's implementation by describing how the lessons demonstrated levels of sophistication according to the categories of the progression.

**Selecting big ideas and treating them as models (score = 1).** For the practice lesson conducted at the summer PD institute, Andy and his group members generated a lesson for an advanced chemistry class on creating a model of strong acids and weak acids. The lesson engaged participants in generating an initial model and then, after an investigatory activity, revising that initial model. Andy's modeling lesson at the institute focused on understanding a discrete concept, strong and weak acids, and was not connected to any "big idea" in chemistry. While several big ideas could have been applied, this was not explicit in the planning or in the implementation of the lesson.

Andy recorded and submitted a model-based lesson that he enacted in the semester immediately following the summer institute. In this classroom lesson, Andy led a "black box" modeling lesson. He began the lesson by stating to his students, "Today we are talking about models" and proceeded to engage them by asking them, "What is a model?". Before much discussion could take place, he passed out a handout with pictures of different items and then discussed if each one was a model. This activity was used during the PD institute as an activity intended to engage students in broadening their understanding of scientific models. Following this discussion, Andy began a classroom demonstration of a "black box" type in which he used a tube with several holes, a few marbles in it, and strings hanging from it. He began by pulling a string and eventually a marble fell out of one of the holes in the tube. He then added the marble back to the tube, pulled a different string and the marble fell out of a different hole. After several minutes

of demonstrating the different possible outcomes, Andy prompted the students to generate a model that would recreate the demonstration. He provided modeling materials to pairs of students and instructed them to try to create a model that behaves similarly to the demonstration apparatus. Students worked in small groups using the materials to make a replica model while Andy continued to use the demonstration apparatus to illustrate the phenomenon again. After students had worked on creating their own models for about 20 minutes, Andy asked one group who had made a model that replicated the demo model to share about how they made their model. Andy then asked the rest of the students to take their models apart because class was ending.

Other than the group who was able to replicate the demonstration model, Andy did not press students for explaining why or how the apparatus worked. Although Andy talks explicitly about scientific models, the goal of the lesson seems to have been to engage in replicating a “black box”. Students constructed replicas, with the same materials that the demonstration was constructed, tested them through trial and error, and finally one group arrived at a replica of the demonstration. While this lesson could have been used to engage students in discussions about the Nature of Science, the lesson failed to engage students in thinking about the process of modeling, the nature of scientific investigations, or connecting the activity to any curricular topic. Andy seemed to have engaged in modeling for the sake of modeling and not for the learning of a concept in chemistry.

**Attending to students’ ideas (score = 2).** Andy’s institute lesson group began their lesson by having the participants generate an initial model of their understanding of strong and weak acids. However, the lesson did not return to this initial model nor were



participants' ideas used to inform the instructional decisions made throughout the rest of the activity. Other participants noticed this and pointed out during the debriefing session following the activity. They noted that Andy's group may have lost site of the purpose of the initial model beyond identifying student's previous knowledge.

This pattern was also noticed in the classroom observation video. Andy solicited student ideas about models at the beginning of the lesson. However, it was not evident that this was intended to be a formative assessment that would inform how he proceeded with the rest of the lesson. Andy did not return to these initial ideas but proceeded with the original plan for the lesson.

**Choosing activity and framing intellectual work (Score = 2).** One of the goals of Andy's institute lesson was for the participants to discover a science concept, the similarities and differences between strong and weak acids, for themselves. While this is an overt departure from using the standard "scientific method" approach, Andy's group tended to leave the meta-modeling knowledge implicit. For example, they did not engage the participants in exploring the reasoning behind why changing a model is connected to scientific processes. Considering how Andy's views of science are aligned with "the scientific method", attempting to lead a lesson that is not strictly tied to TSM demonstrated some progress for Andy and his instructional practice. However, it seems that diverging too far from a stepwise process was challenging for Andy.

Again, this was evident in his classroom lesson. While the black box activity did not adhere to strictly to the stepwise process of "the scientific method", Andy's lesson was focused on achieving a specific end goal, the replication of the black box. Without

explicitly discussing the process the students employed or connecting that process to the work of scientists, the lesson was more of a “proof of concept” type of lesson focused on generating a replication of a phenomenon than it was a “modeling for understanding” type of lesson.

**Pressing for explanation (score = 2).** As many of the groups did, Andy’s institute lesson group attempted to use some of the questioning strategies that were discussed and modeled during the institute. Pressing was one strategy that was demonstrated and Andy and his other group members were attempting to employ this strategy. So, while they were pressing participants to explain their reasoning, they were not pressing participants to provide evidence based arguments or explanations. Similarly, Andy’s classroom lesson lacked this press towards more evidence-based arguments. During the time when students were making their models of the tube and string apparatus, Andy did not engage them in recording the data they were basing their decisions on or engage in any discussion about their thinking. While the activity was more cognitively demanding than simply following procedures that are given to students, the lesson did not engage the participants in making sense of the phenomenon or developing an explanation. The participants were only engaged in generating a replica of a black box phenomenon, which is not scientific modeling but more like replicating.

In summary, Andy attempted several strategies that made scientific models more prominent in his classroom. He engaged students in a discussion about scientific models through the use of a PowerPoint presentation. He also attempted to build on this presentation through the use of a worksheet on models that further developed students understanding of different types of models. He also made an effort to engage students in

the making of a model through the black box activity. While proficient modeling was not achieved, Andy's efforts indicate the emergence of scientific modeling in his classroom practice.

### **Andy's Use of Questioning to Facilitate Modeling Discourse**

Andy's use of questioning was determined by using the EQUIP discourse rubric to analyze recorded video of Andy's pre-institute classroom lesson, his enactment of the small group developed modeling lesson at the summer PD institute, and a video recording of his post institute, in-class modeling lesson.

Andy submitted a video of himself conducting an introductory lesson on models prior to the summer institute. The general teaching style of this recorded class was a traditional didactic whole class discussion facilitated by a PowerPoint. He began by standing at the front of the room and remained there for the majority of the class. The students were seated in long rows at individual desks. His questioning often elicited little more than one word answers from his students and he often responded with a yes or no. If students did not arrive at the answer he was expecting he quickly gave them the answer he wanted to them to hear. This represented a typical I-R-E pattern for the majority of the class. For example, his lesson began with a demonstration involving two pieces of glass sticking together as a result of colligative properties. He solicits ideas from students about why they are sticking together. After several responses from students including, magnetism and sticky stuff, Andy responded to both ideas with, "No", and begins to describe colligative properties. In his use of the glass models as a model for colligative properties, we see his limited view of models as tools for demonstrating ideas through an

analogy. The glass plates and the behavior of sticking together were used as an analogy for colligative properties.

After analyzing the lesson that Andy and his group members enacted at the institute, this reliance on a didactic, traditional teaching style continued to be evident. The activity started with students making an initial model, and then the information in between this initial model and the subsequent revised model was delivered through verbal discourse. During the lesson, Andy was observed practicing different questioning strategies such as rephrasing questions, having students start with what they know, checking for understanding, asking guiding questions, and providing opportunities to change their model. In the debrief discussion, other participants noted that Andy may have provided answers too early thus impeding some of the learning that would be possible through the modeling process. Several times, Andy used a “fill in the blank” style of questioning. This method was not used in the institute because of its propensity to undermine the message that more than one model can be acceptable. This reliance on direct instruction became apparent again in his classroom example lesson.

When analyzing Andy’s recording of his post-institute lesson, there were several improvements in his use of questioning. He was attempting to engage students in a more open form of learning with small group work being the dominant strategy. However, he often responded quickly to students with either answers or low-level probing questions.

Andy’s summative score for questioning was determined to be a 2 which is described as “Developing”. This score indicates that Andy was observed trying different strategies but was not always effective in their use.

## Andy's Growth Network

I chose to use the Interconnected Model of Teacher Professional Growth (IMPG) as an analysis tool that would allow me to further describe different aspects of each teacher's progression to implement model-based teaching and relate these aspects to their growth over time. The IMPG framework was used to guide the development of a growth network diagram that represents how the enactions and reflections of the teacher are situated within four domains of teacher growth. This analysis served to clarify and tease out relationships that deepened my understanding of the progression of model-based teaching implementation. Analysis of Andy's growth network revealed how his pattern of change was focused on his own personal domain. In the following section I will describe his growth domain and the sequences of enactions and reflections that led to this finding.

In the first few days of the summer institute, Andy began to recognize that modeling provides a very different view of the process of science than "the scientific method". On the daily reflection following day two of the institute, Andy states he has a "greater understanding of the difficulty involved in describing the scientific process". He seems to be coming to terms with the fact that this is not the scientific method and seems to be struggling with how to bring this new method into his view of science. This represents the first sequence in Andy's growth network as marked by number 1 in Figure 5.1. The activities of the professional development institute have instigated Andy to reflect on his understanding of science as it was defined by the scientific method prior to attending the institute.

At this point, Andy also recognizes how this scientific modeling process will allow him to better “engage his high risk student through model based inquiry”. This statement, although linked to students, is anchored by his framing it within his own ability to engage students. This reflection represents the second sequence in Andy’s growth network as marked by number 2 in Figure 5.1. He is reflecting on how students will benefit but from the perspective of his own teaching and how it will allow him to better engage students, not how students will be better engaged.

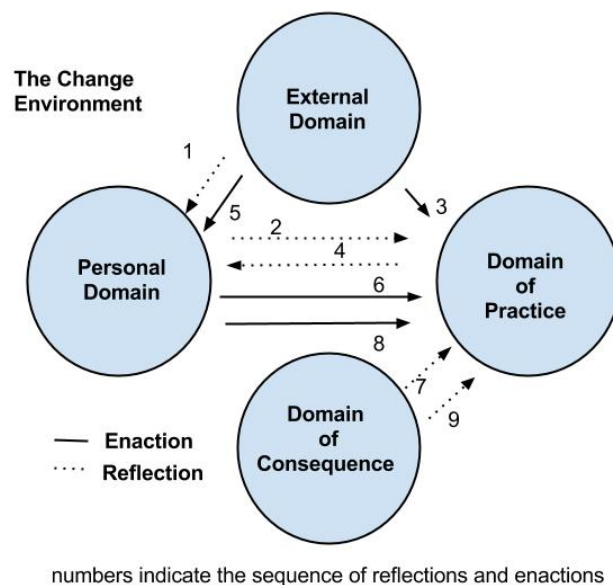


Figure 5.1 Andy’s growth network.

During the practice teaching activities, Andy co-constructed a lesson for an advanced chemistry class on creating a model of strong acids and weak acids. The lesson engaged the other teacher-participants in generating an initial model followed by revising that initial model. Andy was observed practicing different questioning strategies such as

asking participants to rephrase another participant's question, checking for understanding through re-voicing, and asking guiding questions rather than providing answers.

However, as participants began to struggle in making revisions to their models, Andy ultimately delivered the information participants needed through direct instruction.

Several times, Andy used a "fill in the blank" style of questioning, a strategy that was not encouraged at the institute. Andy reflected on these model lesson activities by saying he thought they were helpful but found the other teachers' lessons to be "a little ragged".

This statement seems to indicate that he was distracted by the other participants' first attempts at implementing the modeling strategies. Despite this observation, he did state "the opportunity to observe them [other teachers' lessons] was valuable." As a result of his implementation and his subsequent reflections about the activities, it seems that Andy is struggling with allowing the learning to be self guided rather than guided by him.

His participation in the practice teaching activity represents an enaction from the External Domain (ED) to the Domain of Practice (DP) while his subsequent reflection focused on his own teaching, represents a reflection from the Domain of Practice (DP) to the Personal Domain (PD). His practice implementing a lesson and his subsequent reflection on his ability to do so represents the next two steps in Andy's growth network as seen in Figure 5.1 and numbered 3 and 4. His implementation of a modeling lesson at the institute represents an enaction of the new strategies to which he has been introduced. His thoughts about the other participants' lessons and his own implementation constitute a reflection. Andy later expressed that the most valuable part of the institute was being able to participate as a "student" in the introductory modeling activities.

As a result of his participation in the institute, Andy's knowledge of models as measured by the post institute KSM indicate that his knowledge of models and modeling improved. Although the improvement was small, (0.3 on a scale of 1–4) it does constitute growth and is represented in Andy's growth network as number 5.

Following the institute, Andy describes his classroom implementation of a modeling lesson during a phone interview. He described how he is now using modeling as a formative assessment tool. He described the change in his way of engaging kids in sharing their ideas all together rather than one at a time. He identifies how students were looking at other students work and making changes to their own drawings. He recognized this as effective instructional method because the activity enabled him to deliver content while simultaneously using formative assessment. He stated,

So that worked really well. The kids enjoyed that very much. And then the other kids who were watching that, who may not have had as good an understanding of things, you could see they were taking it in with much greater interest than it would be if I was just up here trying to draw a picture. So I was really impressed by this first initial use of what we studied, the techniques that we studied.

This comment illuminates how Andy sees modeling supporting his ability to deliver content. He identifies student learning when he describes students, "taking it in". This situation represents the next step in Andy's growth network numbered "6" in Figure 5.1, an enactment from the Personal Domain, his new belief in the power of modeling in his classroom, to the Domain of Practice (DP), using modeling as both a teaching and assessment strategy. In this comment from his post institute interview, Andy clearly articulates how he now, from experience with his kids, has seen how engaging students in a modeling process engages students to the point of "having fun" as opposed to him simply being "up here trying to draw a picture." He is coming to understand that



engaging students in working together fosters greater engagement in his lessons.

However, again we see Andy talking about students and drawing on his observations of them but framing his observations around his own actions as the teacher. This represents the next sequence in Andy's growth network, number 7 in Figure 5.1.

For his classroom observation lesson, Andy stated that the lesson he used was one he had done for about 4 years. The black box lesson, which involved the tube, string, ball apparatus describe above was one in which students need to observe this “phenomenon” and then generate their own models that work in the same way. When asked how this lesson is different as a result of him attending the summer institute he explained that he followed the activity with a PowerPoint with explicit information about models and what scientists use them for in science. So although he plans to talk more explicitly about models and their use in science he is planning to do it in a very traditional, direct teaching approach with little change to what he has already been doing. He goes on to say that he is putting this in after the scientific method section of his course and he explains that the model is the outcome of the scientific method.

So that what we'll do is we'll move from the scientific method into the modeling and say that this is really the foundation of the scientific method is modeling. And, uh, is what the, uh, scientific methods objective is to create a model to work that works in the real world and explain it. I've been doing a little research and all to try and make sure I explain things, uh, you know so they can understand the whole concept. I'm afraid I don't know how to get across some of the, uh, some of the more in depth concepts of what models are used for our physical models, pictorial models and Statistical models and all those kinds of things without doing a little bit of a formal presentation on it.

He recognizes the difficulty in getting the modeling process to align with the scientific method and describes how he will continue to do “formal presentations on it”. Here we see Andy's growing but limited understanding of models impacting his lesson

development. This represents the next sequence in his growth network indicated by number 8 in Figure 5.1. When asked if he plans to do modeling throughout his course or is this the only time, he states:

I guess what I'm doing with this model lesson is kind of what I hope, is kind of a model of how I'll approach the other concepts. When you try to do some kind of a model to introduce a concept. And when I say model, I mean the kids do. The kids use something to create a model, and then. And then at that point...introduce some more detailed concepts in a more formal way. But I guess I'm just gonna have to practice and get better for how to, how to keep the introduced models or, you know, include models in the processes. But so many of the things I use or already use in some form of model. The [models] we do with the electron cloud. The model activities we have [for the] experiment, where they actually use a modeling activity that simulates Rutherford's experiment, and things like that.

Andy is now acknowledging that students' initial models should become a part of the lesson but he is struggling with how to do that. Recognizing this represents a reflection on his practice emanating from his students. This is marked as a reflection from the domain of Consequences on the Domain of Practice, number 9 in Figure 5.1.

In summary, the growth network described above indicates that Andy plans to “include more models” and explicitly talk about model as a part of science. However, he still plans to use modeling as a formative assessment and then “add” the formal content afterwards. He is attempting to integrate models into his understanding of science as the “Scientific Method”. These factors indicate that Andy and his students represent an emergent modeling classroom. Andy and his students are talking about models more explicitly but are not engaging in the process of modeling in a way that resembles how scientists would engage in modeling.

Andy's growth network is dominated by reflections and enactions that connect the Personal Domain and the Domain of Practice. His views of the Nature of Science, his

traditional approach to instruction, and developing understanding of models and modeling, are all contributing to his lack of progression to a more robust implementation of modeling in his classroom. While he tried different questioning strategies during the institute practice lessons, his classroom discourse was almost entirely didactic with little attention to student ideas. This was also evident in his classroom implementation. His knowledge of models and modeling remains limited and his view of the Nature of Science is dominated by “the scientific method” and he struggles to connect modeling within this conceptual framework.

### **The Case of Carla**

Carla is a certified middle school science teacher with 11 years of experience. She has a Masters degree in Reading, which she completed approximately five years prior to this study. On her pre-institute application, Carla indicates her comfort level with her own content knowledge for the courses she teaches as “fairly high”. She also indicates that she is a lifetime learner and appreciates all the help and encouragement she can get. She states that every day she teaches she reflects on her instruction. She asserts that students in her classroom struggle with inquiry, but proudly describes how students leave her class tired from having to think. She indicated that she attends national and regional science teacher conferences every year and participates in district level professional development at the beginning of each school year. She tries to attend as many inquiry sessions as possible. She has attended the local science teacher conference for 10 consecutive years. She seeks out professional development opportunities and states that these activities “invigorate me”. Carla also teaches in a 4 X 4 block schedule. She teaches integrated science, earth science, and life science to 8th graders.

## Carla's Knowledge of Scientific Models

Prior to the summer institute, Carla's knowledge of models and modeling was assessed using the Knowledge of Scientific Models (KSM) survey. According to my analysis of her responses, Carla's level of modeling knowledge initially seemed to be an informed, proficient view of models and modeling. She provided a definition of models that referred to them as, "representing the essential structure of some object or event in the real world, [and are] necessarily incomplete." She elaborated by stating that models can also have multiple forms such as "...physical, as in a model airplane or architect's model of a building or symbolic, as in a natural language, a computer program, or a set of mathematical equations."

Table 5.3

### *Carla's KSM Questionnaire Scores*

	Knowledge of the Nature of Models	Connecting Models to the Nature of Science	Connecting Models with Teaching	Overall Score
Pre Institute	n/a	n/a	n/a	n/a
Post Institute	2	2	3	2.3

Referring to models as symbolic and using natural language as an example of a model would indicate a sophisticated understanding of models. But, upon further review of her responses to other surveys, it occurred to me that her eloquent description of models was not similar to her somewhat confusing description of the Nature of Science

and its relationships to religion, which I will describe more fully in the next section. I later found that several responses to her KSM pre-institute survey above were in fact “cut and pasted” from an online source. When I realized this, I decided to check all of her responses for possible connections to online sources. This resulted in the removal of most of her responses to the pre institute KSM from further analysis. My evaluation of her KSM is based on her post-institute KSM survey responses, her daily reflections from the summer PD institute, and statements she made in post institute semi structured interviews.

**Dimension one: Knowledge of the nature of scientific models.** While establishing Carla’s KSM related to Dimension 1 prior to the summer institute was not easy, in one of her responses, Carla stated “even today, most teachers do not understand the true meaning of scientific models.” In this statement, she seemed to be articulating her own lack of understanding of models. In her responses to the post institute KSM survey, Carla characterized a model as an “accurate representation of the content being taught”. During a post institute interview, Carla articulated how a model must have a purpose and this purpose should be explicit. These statements indicate that she had a developing understanding of models and scored a 2 for Dimension 1 of the KSM survey rubric.

**Dimension two: Connecting models to the nature of science.** Carla identified few connections between the nature of models and the nature of science. This was likely due to her misunderstandings and lack of knowledge about the nature of science. In one response to a question about the similarities and differences between scientific models and teaching models, Carla stated that “students are expected to construct and conduct

experiments to explain concepts and they have no idea of what will be the outcome, so isn't that what scientists are also doing?" This statement is indicative of Carla's naïve understanding of the processes and NOS.

**Dimension three: Connecting models with teaching.** Prior to the summer institute, Carla stated that she used models in the classroom "to [help students] understand [the] content of the standards". She listed models of the eye, ear, and solar system as models she has used in her teaching. After carefully analyzing all of her responses, I found that her view of models did not go beyond the idea of a physical model. She did state that teaching about models is important in her science classroom but provided no evidence that she used models beyond simplifying or demonstrating a complex process or topic.

On the daily reflections completed during the institute, Carla's reflections focused primarily on her deepening understanding of her own knowledge about models and modeling. On her first daily reflection during the institute, she recognized the "importance of a model having a purpose" and that she will "need to consider this in the future" when she uses models in the classroom. During a phone interview following the summer institute, Carla was asked to elaborate on the significance of a model having a purpose. She stated:

You have to think what is the purpose that you are trying to get a child to see. What is the purpose for the model? If I'm – well, we've already talked about astronomy. And I've got these little teeny, the sun, the earth, and a little ball going around the earth. And I got to thinking, around the sun I have another little ball going around it. And if I bring that out to the children and I'm talking about the moon revolving and rotating around the earth, then my children's going to see there's like a moon revolving around the sun. So if I am trying to explain the moon rotating around the earth and days and nights. I'm going to confuse my children with that

model. So I have to think of my purpose, why, what am I trying to model? And make sure my model aligns with what I am trying to get them to understand. You don't just model; you have to have a purpose and it has to go with what you want them to understand or to process.

On the last reflection of the weeklong institute, Carla stated “the purpose and meaning of modeling” was the most significant take away from the week. This discussion indicated that Carla had a new appreciation for the ability of a model to be explanatory and how including too many aspects of a phenomenon may confuse students rather than foster understanding.

Carla's initial and most significant outcomes from the institute are grounded in how they will impact student learning. While she is talking about her own use of models as instructional tools and her own skills with facilitating instruction, both are grounded in how they will impact student learning. So, while she is talking about her own actions, the significance of these actions is firmly centered on student learning. In her reflection on day two, Carla states the modeling has been redefined for her. She recognizes that there are many different types of models and these can be used with inquiry. She sees how students can use models to explain their own understanding and create answers to their own questions and problems.

Based on the analysis of Carla's responses to the KSM surveys and her daily reflections, her level of KSM was given a score of 2 for knowledge of science models which corresponds with a developing understanding of models. Since her knowledge of models prior to the institute was questionable, I assumed that her attempts to cut and paste responses indicate an uninformed level of knowledge of models. As a result of the institute, her knowledge of models and modeling improved slightly.

## Carla's Knowledge of the Nature of Science

Carla's views of NOS are consistent with a "transitional" level of knowledge of the NOS as measured with the VOSE. Determining this classification depends on the percentage of findings about a respondent's knowledge of the NOS that are congruent with the generally accepted understandings of the various aspects of the NOS. Carla did not attain a 70% congruence rate nor did she attain a 70% incongruence rate, thus the transitional distinction.

Table 5.4

### *Carla's VOSE Scores*

Aspect of the NOS	Aspect Understanding Score	Importance of Teaching Aspect Score
Creativity and Imagination	4.4	n/a
Tentativeness	4	4
Theories and Laws	2	2.3
Innaccuracy of TSM	2.3	3
Average	3.2	
Level of Knowledge	Transitional	

**Creativity and imagination.** While Carla understands that imagination plays a role in the processes of science, there is no indication that she sees creativity playing a significant role in multiple activities of science beyond the design of an investigation. Her VOSE score was a 4.4 indicating she certainly agrees with the importance of creativity in science. However, on her VNOS-C response to a question with a similar focus she stated, "[scientists] use their creativity and imagination during their investigations... in planning and designing." She goes on to discuss an example of the design of spacecraft and how multiple designs were tried. So, her inclusion of creativity in the scientific process is



limited to the design phase and she did not indicate any creativity in other processes of science.

**Tentativeness.** Carla also understands that scientific knowledge, due to continuous experimentation, is likely to change over time. Yet she describes science as a set of truths and an effort to describe reality. She goes further down this road asserting that the goals of science and religion are the same, to uncover the truth of reality.

**Theory and law.** Carla has several naive conceptions about science as a way of knowing and a belief in a “truth” view of reality. For example, in her response to a question about her view of science, Carla writes:

Science and religion/philosophy share many characteristics. Religion allows man to gain wisdom, but science allows man to gain intelligence. The path may be different, but the destination is the same. The final goal of science and religion are one and the same: the freedom of man from restraint. Both religion and science both try to describe man and the universe. Religion seeks to teach us the truth and science works to uncover reality. Reality and truth [are] the same thing. Science is the study to uncover the reality while religion is the way to truth.

Carla draws distinctions between science and religion along the lines of wisdom and intelligence. She asserts that reality and truth are one and the same and are the primary goals of both religion and science. This statement is aligned with an uniformed view of science that espouses a hidden truth awaiting discovery. In her attempts to equate religion and science, perhaps unknowingly, Carla contradicts many of her responses to other survey questions. For example, in responding to a question about Scientific Theories, she states:

Theories are simply used to explain certain observed phenomena that have been proven to some degree and are a conjecture or educated guess. We have theories because it is a systemized way to try to get to another theory. Science is an ongoing study to ever changing phenomena. Another example of theory change is the theory of the evolution. The theory of man evolving from tadpoles and the theory of humans evolving from

monkeys are very debatable issues. Each theory has enough evidence to give weight, but neither has been proven. Science is changing rapidly because of technology and what we believe today may be obsolete tomorrow.

Again we see in this comment an example of how Carla perceives a theory as an “educated guess”. This is a common misconception when referring to scientific theories and demonstrates her uninformed views of the NOS. Further demonstrating her uninformed view of NOS is her naive views of the theory of evolution and the origin of life. She is comparing theories about human origins from tadpoles or monkeys as competing theories. This example, while severely inaccurate, does demonstrate that she sees theories as debatable but more as educated guesses rather than ideas supported by substantial evidence.

**The scientific method.** In addition to significant misconceptions about scientific hypotheses, theories, and laws as well as the relationship among them, Carla has an uninformed view of NOS as a result of her adherence to a strict interpretation of the process of science as defined by TSM. In a response to the VNOS-C questions, Carla states that, “Science is a systematic study explaining the creation of the universe to the existence of life as we know it today.” Again we see some narrowly focused views of science that are grounded in the term “systematic study” indicating her adherence to TSM. Her VOSE responses indicate that she sees TSM as the primary process of science but she does not seem too committed to teaching it exclusively as indicated by a VOSE score of 3 for the importance of teaching TSM.

### **Carla’s Implementation of Model-Based Teaching**

I characterized Carla’s implementation of modeling using the Performance Progression for Model Based Inquiry (Thompson, et al., 2009). Carla’s institute modeling

lesson and subsequent classroom modeling lesson were the primary data sources for this analysis. For the quantitative portion of this study, I scored Carla's implementation of model based teaching as a 2. A score of 2 indicates that some aspects of modeling are being employed and that progress can still be made in terms of the continuum of practice described by the Performance Progression. In the following section, I subdivide my description of Carla's implementation according to the categories of the progression.

**Selecting big ideas and treating them as models (Score = 2).** During the summer institute, Carla was the first teacher to practice her modeling lesson. Her lesson engaged institute participants in generating a model that could, "explain the data on the phases of the moon". The data was a set of images of the moon taken each day over the course of a month. It included images that began with a new moon, continued through full moon, and back to a new moon. This lesson, focused on understanding and explaining a dynamic process. However, Carla did not situate this work within the context of answering a guiding question or further understanding of a big idea in science.

During her post institute classroom observation, Carla's classroom lesson was situated within a unit on the geological history of earth in her 8<sup>th</sup> grade earth science course. The lesson involved students in generating a model that could describe Earth's history over a geological time scale. Her discussions with students focused on how different representations for a known phenomenon could be used for different purposes. On the day of the observation, students were in the process of generating their models. The observed lesson began with Carla and her students moving around the room, observing and evaluating student-generated models of the geological history of earth that had been created in the days before the observation by a different class of students.

Several models were in the form of diagrammatic models on poster paper, which were hung on the walls. One model was a 3D model, a diorama style model where a viewer could peer through a hole and see “back in time”. Carla engaged students in evaluating these models by comparing them to one another and to a model provided in the textbook. After working their way around the room with Carla, students returned to their small groups and continued working on the models they were making.

In both lessons, Carla was engaging student in several modeling activities including evaluating models, revising models, and generating models. However, neither her classroom lesson nor her institute lesson made clear connections to big ideas in science. The connections were certainly implied, but no evidence was found that the big ideas were made explicit to the learners. The lessons she chose to enact could have easily been modified to focus on big ideas but the big ideas were left implied rather than made explicit.

**Attending to students’ ideas (Score = 3).** During the institute activity, Carla began by showing pictures of the moon taken each day for one month. Carla then asked the participants to generate a diagrammatic model on a whiteboard that would explain the data. As participants worked on their models, Carla circulated around the room, using the discourse techniques she had learned about during the institute. These included asking participants to explain their thinking and reasoning through the use of their model. What she learned from these small group conversations was used to guide the whole group with periodic announcements for clarification on the task. Towards the end of the lesson, she used what she had learned about the participants’ thinking to sequence the share out of the small groups through the presentation of their white board diagrams. She began with

the most simple diagrams and progressed to the more complex models. While this sequence was not perfect, she did attempt to use student ideas to adapt her instructional implementation.

In her classroom lesson, Carla was soliciting student ideas about each of the models of geological time. She pressed students to explain their evaluation of each model. While the focus of the lesson was more on a specific topic rather than the underlying processes, she was adapting her instruction through a focus on students' ideas about the models. On several occasions, she asked students to build on the ideas that another student had raised and then asked the class to consider these ideas as they finished constructing their own models. She earned a three overall because of her attention to student ideas and the efforts she made to adapt the lesson to these ideas.

**Choosing activity and framing intellectual work (Score = 2).** In her institute lesson, Carla engaged participants in generating a model that could “explain the data”. In this lesson, the data were images of the moon taken over the course of a month. Participants were prompted to develop a model that would explain the pattern in the pictures.

In the classroom lesson, the goal was for students to generate improved representations of an accepted understanding of the geological history of Earth. Students were engaged in generating evaluating, and revising models. However, the focus was on the communicative and descriptive nature of the models. Her focus did include the big ideas represented by the models. In other words, the focus of the lesson was not on the ways that models could be explanatory of how or why things changed over time. As such,

the activity was more about better representing confirmed ideas rather than building understanding of models as being testable and conjectural.

**Pressing for explanation (Score = 2).** Although Carla’s two lessons may have missed the mark in terms of focusing on a big idea, Carla was pressing students to explain their thinking as they evaluated the models and their data. She was encouraging students to explain their reasoning behind their evaluation of the models and pushing them to think deeply about the models’ explanatory power. However, without the connection to the big ideas, student explanations did not push past “what happened”. While the lessons did have the potential to do this, Carla’s implementation missed opportunities for students to engage in deeper evidence based explanations of the underlying causal mechanisms.

In summary, Carla was engaging students in multiple aspects of the modeling process but did not push participants or students to predict or explain the causal mechanisms underlying the explanation the models were providing. Carla used the modeling cycle to foster student understanding of the explanatory nature of models, not the predictive or investigative aspects of modeling as a process of science. Carla was adopting many of the strategies and techniques associated with modeling yet not making the explicit connections between the content, the big ideas, and the modeling process. With an overall score of 2 as determined through analysis using the performance progression, Carla is considered to be at the developing level of modeling implementation. While this is the same general category as Andy, Carla seems better positioned to advance in her implementation due to her willingness to experiment with a new instructional strategy and her ability to facilitate classroom discourse.

## **Carla's Use of Questioning to Facilitate Modeling Discourse**

Carla submitted a video of a lesson she had conducted prior to coming to the summer institute as an example of her level of use of models to teach science. Based on the analysis of the video, I determined Carla's level of questioning using the EQUIP discourse rubric to be a Level 3 which is associated with a Proficient level of use of questioning. Carla has been teaching for 11 years. Her questions were almost entirely open-ended questions during her institute lesson as well as her classroom modeling lesson with few lower level, recall questions. Her style of teaching demonstrated a range of strategies that supported and facilitated her use of questions to elicit and extend student thinking. She used a variety of grouping structures to support different conversations by moving students from whole class to small group activities. She also varied the level of her questions from recall to analysis levels and did so in order to support student's individual learning. Carla's use of grouping structures and questioning supported students as they engaged in the activity. However, the questions and the conversation rarely drew on scientific knowledge or scientific ways of thinking.

During the in-class observation following the summer institute, I observed Carla engage students in a discussion comparing two student-generated models. She asked, "Which one of these models did you learn more from?" After listening to several student responses, she used follow-up questions that probed students thinking such as, "why do you think that?" In most discussions, she consistently engaged students in considering other students' ideas. Once a student had described their thinking, she would ask another student to interpret what the first student had said and then add their own understanding

to the conversation. These techniques, which were covered at the summer institute, helped her maintain the focus of her questioning on students' ideas.

During Carla's classroom lesson, her questions were typically at the analysis level as she asked students to share their ideas about geological time models they had been making and explain their thinking. The atmosphere of this discussion fostered students' comfort with asking each other questions and asking Carla questions. Students were observed asking each other probing questions and there seemed to be a high comfort level with this peer- to – peer questioning. This indicated that Carla had been fostering this community long before this observation. Thus the discussion seemed very conversational with multiple ideas being shared and Carla using these ideas to guide the conversation.

It was evident that she was pushing her own practice to embody many of the techniques she learned about at the summer institute. There were times when she would evaluate a model before giving students an opportunity to evaluate it. This led to the students' discussion mirroring Carla's interpretation. She appeared to recognize this and in a subsequent portion of the discussion, when they had moved on to a new model to evaluate, she stated, "tell me what you think before I tell you what I think". In saying this, I believe she recognized the impact of her evaluation coming before student ideas had on the conversation. In fact, she had made a comment on one of the summer institute daily reflections, stating that she was "recognizing the importance of questioning students and not always providing the direct answer but probing and re-voicing student ideas." This mid-course correction within the lesson demonstrated her increased awareness of the importance of questioning to her facilitation of the lesson.



## Carla's Growth Network

Through the process of generating Carla's growth network using the IMPG, I recognized several differences between her growth and Andy's growth. In the following section, I will describe how those differences indicated a very different growth network and what these differences might mean for her implementation.

Carla's reflections on her own skills and knowledge, grounded in how they impacted student learning represent the first three growth sequences in Carla's growth network, indicated by numbers 1, 2, and 3 in Figure 5.2. While the first two sequences are reflections on her own knowledge and skills facilitating classroom discourse, her reflections immediately turn to how her new skills and knowledge will impact student learning.

During a post institute interview, Carla stated that participating in the institute has led her to try to incorporate modeling into all of her teaching. When asked what part of the institute was the most significant to her change in instruction she talked about her experience during the practice teaching session. She commented that peers made comments about the activity that she recalls. She recognized how she needs to be more prepared for what students might say; she needs to anticipate what kinds of questions they might ask. Upon reflecting, she thought it would have been best to have a 3-D model that could have helped different students. Here again, the most meaningful activities of the institute are framed within how her learning will impact students' learning in her classroom and what steps she needs to take in order make those benefits real. Her enaction of what she learned during the institute, the subsequent reflection on her own

learning, her own practice, and framing around student impact, represent Carla’s next growth sequences, 4, 5, and 6 in Figure 5.2.

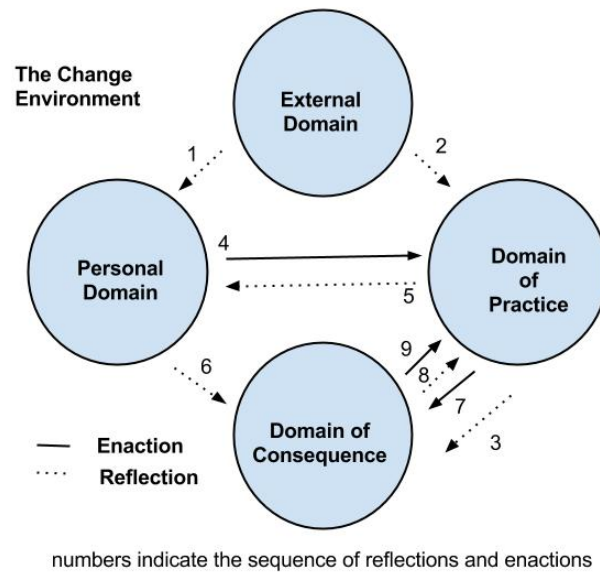


Figure 5.2 Carla’s growth network.

During a phone interview preceding her modeling lesson observation, Carla described how she had been engaging her students in a sequence of modeling so far that year. She described how she had been beginning units by having them draw their understanding. As an example, she spoke of a lesson in which students drew their understanding of Earth’s layers and how earthquakes are formed. She allowed students to draw any type of model they felt would work to explain their understanding. The variety of models included verbal models, diagrammatic models, and mixed verbal diagrammatic models. The students began by making posters with drawings of their initial ideas as a

descriptive model of what happens during an earthquake. Students then went to each other's posters and added notes about things they liked and things they didn't understand. Students then had to redraw their models as their understanding changed and address the comments from their peers. Carla said this went through 4 rounds of revision. So, Carla engaged students in several aspects of the modeling cycle. The students were generating a model, critiquing a model, and revising a model. Carla believes that modeling fits into almost all of her units in some way although, as she states, "The challenge is figuring out how."

This method of implementing the modeling cycle was seen again during her classroom observation. During the classroom observation, Carla's lesson engaged students in a "gallery walk" activity. In this activity, students were moving in a group around the room observing and critiquing student generated models that described the history of life on Earth. Carla explained to me later that this lesson was inspired by students commenting on the ineffectiveness of a model for this content in their textbook. The textbook model showed different organisms associated with different eras of geological history. The students noticed that the time spans, although very different in number of years, were all equally sized and spaced in the textbook model. Upon probing student thinking, Carla realized that students did not understand the differences between the time span of each era. For example, students thought that the current era was equally as long as previous eras even though it was very much shorter than the others. Carla decided to let students make models that they felt were better representations of the history of life on Earth. While some student models simply recreated the textbook model, several student models used a scale that could better account for the differences in time

span of each era. As students were walking around, their comments included observations about the purpose of the model and how some were better able to achieve this purpose than others. Students noticed that models that involved scale were more explanatory than those that did not include a scale.

Carla's implementation of modeling in her classroom represented the final growth sequence in Carla's growth network. She took what she had learned about models and modeling, developed lessons that drew on a modeling framework, and grounded her implementation in the feedback she received from students. So, an enactment in her domain of practice leads to her students learning about models and the process of modeling, and the feedback from students guides Carla's instructional strategies as she seeks opportunities to integrate modeling into her teaching. These sequences are represented by numbers 7, 8, and 9 in Figure 5.2.

While Carla engaged students in generating, evaluating, and revising models, this activity did not engage students in using their models to make predictions or explain why these eras were considered different. This modeling episode was all about generating a new representation of known content. Students were only learning about better ways to represent known content. They were making a better descriptive model. The modeling process they engaged in did not lead to generating new knowledge about content, only organizing knowledge they had already acquired and generating more informative representations.

Especially interesting is that this type of peer evaluation was not introduced at the institute. Carla has taken her understanding of the modeling process and expanded on it to make it more meaningful for her students through incorporating other instructional

strategies thus making the process more effective. She attempts to engage students in revising their models based on other student's critical feedback rather than on empirical data. Since the content was the geological history of Earth and student generated data would be quite difficult to obtain, this decision seemed appropriate for this content.

Carla's growth network represents a considerable step forward beyond Andy's level of implementation. Several components of full modeling inquiry are present yet the focus on a big idea is missing. Carla is attempting to engage students in all stages of the modeling cycle but in so doing is focusing on the cycle rather than on the reason for engaging in each cycle. Students are learning about the purpose of models and coming to more informed understanding of the process of modeling. However, this example is not leading students to generate new knowledge in ways that emulate scientific processes. Carla has taken what she has learned about scientific modeling and added some components of modeling to her existing instruction. This layer includes the purpose of models, multiple models, and evaluation of models. However, all of this involved using models as explanatory tools but not as predictive tools, which would have indicated more progress.

### **The Case of Laurel**

Laurel is a high school science teacher in her fourth year of teaching. She has taught a variety of science courses in that time but at the time of this study, was teaching AP Biology and Physical Science. She has earned a BS in Biology and was working on her Master's degree in Educational Leadership. She is considered "highly qualified" by her state and is certified to teach Biology and General Sciences. Laurel has attended a number of different workshops 2-3 times per school year and 2-3 workshops during each

summer since she began teaching. Her school is on a 4X4 block schedule, which requires her to teach three 90-minute classes each day. At the time of this study, this meant one section of AP Biology to 10th and 11th graders and two sections of 9th grade Physical Science. Her classes average 25 students and she is teaching at one of the more affluent high schools in her district.

She was drawn to the Model Based Inquiry Summer Professional Development Institute by a motivation to become more experienced with an inquiry style of teaching as a result of the emphasis on inquiry in her curriculum standards and materials as well as an intrinsic motivation to serve diverse learners. On her application she noted, “the district curriculum map is grounded in inquiry teaching. However, I have never attended a professional development program that includes inquiry.” She goes on to state that “Inquiry is a model that can be very beneficial for all students and I want to learn more about it.” When asked why she wanted to learn about scientific modeling, she states that she thinks, “students benefit from it” but did not expand on why. It will become clearer through this case description, how important this focus on student learning is to Laurel and her modeling progression.

### **Laurel’s Knowledge of Scientific Models**

Analysis of Laurel’s pre-institute KSM survey responses indicated that her KSM was uninformed prior to attending the summer institute. After attending the summer institute, Laurel’s KSM improved according to the KSM survey rubric and was assigned a score of 2 indicating a developing level of KSM with subdomain scores of 2, 2, and 3.

Table 5.5

*Laurel's KSM Questionnaire Scores*

	Knowledge of the Nature of Models	Connecting Models to the Nature of Science	Connecting Models with Teaching	Overall Score
Pre Institute	2	1	1	1.3
Post Institute	2	2	3	2.3

**Dimension one: Knowledge of the nature of scientific models.** Prior to the summer institute, Laurel defined the term scientific model as “a representation of a concept”. She states that in order for them to be high quality they should be “clear and multidimensional”. She describes how she engages students in modeling by having students collect data and create a model to represent their data, primarily during laboratory activities. She states she uses models to, “supplement the science standards”. She also stated that models are a “great way to teach ESL students” who struggle with language issues. In response to a question that probed her understanding about the relationship between scientific models and models used in the classroom, she stated that the models should be the same but the cost of the scientific models may be too great for a school to afford. These comments indicated that Laurel sees models as descriptive and explanatory teaching tools. In other words, models are used to facilitate understanding of a curricular concept or as a representation that makes data more easily understood rather than as predictive tools that can be used to explore and learn about the unseen

mechanisms that lead to observable phenomena. She does not elaborate on any connections between a model and its target beyond accuracy being an important quality.

As a result of attending the summer institute, Laurel deepened her understanding of scientific models and how the process of modeling could be used in her classroom. Her definition of a model became more robust when she stated after the institute, "...before I went to the Institute I didn't really have a clear idea of what modeling or models were. I used models kind of like lab equipment to set up or simulate an experiment or a bigger scientific concept. I now understand a scientific model is a representation of a concept, idea, or process. It should have a purpose in student learning." By purpose, Laurel is referring to one of the main emphases of the summer institute which promoted that models are developed by scientists with a specific purpose in mind. So, multiple models for the same phenomenon can and do coexist. Which model is used depends on the purpose for which it will be used. After the institute, she recognized that the purpose of models goes beyond simply representing and can include conceptual understanding of ideas rather than just physical phenomenon. It was also evident that Laurel came to see how models could be used as investigative tools. During her classroom observation, she engaged students in a modeling cycle that required them to generate a prediction that was grounded in their own personally generated model. As a result, Laurels final score in dimension 1 was designated a 2 and is associated with a developing understanding of the nature of scientific models and modeling.

**Dimension two: Connecting models to the nature of science.** Laurel made few references to the NOS in her responses to the initial KSM survey. However, on the second administration of the survey following the summer institute, she did indicate that



a quality of a model was that it was “revisable.” This statement indicates that her understanding of models now included a tentative aspect and this indicates an expanded view of a model beyond something that needs to be purchased in a “correct” form. On her daily reflection from day 2 of the summer institute, Laurel stated, “I will spend more time on teaching the Nature of Science”. So, while it was difficult to pinpoint Laurel’s growth in her understanding of the connection between models and the NOS, this reflection indicates that she found a new value for teaching about the NOS. As a result, her score for this dimension was a 2, again, indicating a developing understanding of role of models in science.

**Dimension three: Connecting models with teaching.** Prior to the summer institute, Laurel was only using models to demonstrate concepts or help students better understand topics in her curriculum standards. On the KSM survey prior to the institute, Laurel stated that she would “use [models] in lab activities to apply the concept they learn in lecture”. This was evident in her pre-institute modeling video in which she engaged students in using a molecular modeling kit. As a result, her knowledge of student ideas about models focused on students seeing models as a “demonstration... or something they can manipulate”. When asked to elaborate on this, Laurel stated, “I really don’t know why they think this, I have never asked. Also, I do not fully explain what scientific models are and why they are used”. These statements indicated she had an uninformed understanding of how models can be used in the classroom prior to attending the summer institute.

During her practice-modeling lesson implemented at the institute, she began the lesson by explicitly discussing models and their purpose in science. She followed this

with several rounds of model building in order to scaffold the participants understanding of the periodic table as a model of the patterns that could be used to predict the characteristics of the elements. In a post institute interview, she stated that she now includes a day, at the beginning of the school year, explicitly focused on the importance of models and modeling in both science and in learning, more generally. She discussed how she uses models to engage students at the beginning of a lesson through having them draw a picture of their current understanding. This allows her to better plan her unit based on the preconceptions that surface. While it was evident during the first classroom observation that she still struggled with engaging students in using these initial models as predictive tools, the fact that she had integrated model building into her teaching so extensively demonstrated her new appreciation for the roles of scientific models in her teaching. As a result, Laurel's score for this dimension of KSM was a 3, associated with a proficient level of understanding of the connections between models and teaching science.

### **Laurel's Knowledge of the Nature of Science**

Laurel's understanding of NOS is categorized as a "transitional" understanding as measured with the VOSE. Someone with a transitional understanding of NOS may have some more informed views of specific aspects of NOS while at the same time harbor uninformed views or even misconceptions about other aspects of NOS. While Laurel certainly has a few misconceptions, she is in the upper range of the "transitional" categorization with an average VOSE score of 3.1 for the aspects of NOS relevant to this study.

Table 5.6

*Laurel's VOSE Scores*

Aspect of the NOS	Aspect Understanding Score	Importance of Teaching Aspect Score
Creativity and Imagination	4.6	n/a
Tentativeness	3.7	5
Theories and Laws	1.8	4.8
Role of TSM	2.1	1.4
Average	3.1	
Level of Knowledge	Transitional	

**Creativity and imagination.** Laurel understands that science is imaginative and supports the role of creativity throughout the processes of science in both her responses to the Likert-type questions on the VOSE as well as her response to the open-ended VNOS-C question. She “strongly agrees” with creative aspects of NOS on the VOSE (VOSE score of 4.6) and in her VNOS-C responses to a similar question, she stated:

Scientists use their creativity and imagination throughout the whole scientific process. Real science is not about following recipe type instructions to get data and that's it. Science is about designing an experiment, collecting data and forming conclusions based on the data. There are many ways to arrive at the same (or similar) conclusions so the planning and design may require some thinking. Also, the data that are collected can be interpreted a little differently and that may require some imagination. Interpretation of data can vary in some cases. Quantitative and qualitative data can [be] used to make inferences, which is why creativity and imagination are important characteristics of scientists.

The ideas she raised in the above statement indicate that she sees creativity and imagination playing a critical role in most aspects of science.

**Tentativeness.** Laurel's responses to VNOS-C and VOSE questions indicated that Laurel understands the tentative aspects of the NOS in a variety of ways including

the tentative nature of theories as well as the tentative nature of data. In one of her responses to the VNOS-C questions, Laurel states,

Theories change because new evidence is discovered with the advancement of technology. Theories should be learned because they reflect the most current data about the topic. If we don't learn the present theories we will never be able to make advances from that point.

In this statement, Laurel describes the tentative nature of theories in relation to the data on which they are based. She understands that as technology advances, it allows for more complete data sets. As a result, theories are likely to change. She emphasizes the importance of understanding the current theory in order to make future theories more informed. This appreciation for the former theories demonstrates her view of the importance of theories being connected to other theories and counter arguments in science.

**Theory and law.** One of the problematic aspects of her view of the NOS is that Laurel misunderstands the relationship between hypotheses, theories, and laws. A score of 1.8 on the VOSE questions that address this aspect of the NOS indicated that she has a significant misconception about the relationships among Scientific Theories and Laws. Based on an analysis of her response selections on the VOSE, Laurel agrees with a hierarchical relationship in which laws are supported by more evidence than theories. Although she has this misconception, “she strongly agrees” with the importance of teaching this relationship.

**The scientific method.** While Laurel’s informed understanding of the tentative and imaginative aspects of NOS is evident, many of her statements are connected to her beliefs about “the scientific method” as determined by her responses to questions on the

VOSE focused on the importance of TSM. Scoring a 4.6 out of 5 on a question probing the importance of teaching with TSM, Laurel demonstrates that she “strongly agrees” with teaching students about TSM. She seems to understand how creativity can support each step in scientific process but nevertheless, there is a strict order through which science progresses.

### **Laurel’s Implementation of Model-Based Teaching**

Laurel’s pre-institute video provided me with a baseline level of her ability to implement model-based teaching to go along with the institute lesson and the classroom lesson. Based on my analysis of these three instances of model based teaching, I determined that Laurel progressed from an unsophisticated level of model-based teaching to a sophisticated level of model-based teaching over the course of this study. In the following section, I will describe Laurel’s implementation ability in terms of the categories identified by the Performance Progression for Model Based Inquiry (Thompson, et al., 2009).

**Selecting big ideas and treating them as models (Score = 4).** In her pre-institute lesson, Laurel engaged students in the use of ball and stick models to learn about molecular geometry and structure. Analysis of this video indicated that, prior to the summer institute, she was using models exclusively as representations of other things and not using them as tools for predicting or explaining phenomena. She stated that her goal for this lesson was for students to be able to recognize different representations of molecules and considered the lesson to be successful. Her goals for the lesson did not include explicit references to any big ideas in chemistry. While the lesson did focus on

unobservable entities, no connections were made to any observable phenomena nor did Laurel refer to any underlying mechanisms that determined molecular shape beyond the positioning of the holes for the sticks to fit into each “atom”. The modeling kits were used as physical models to visualize molecules that are too small to be seen directly.

During the institute, Laurel participated in the group developed modeling lessons and was observed explicitly introducing models, asking probing questions, and engaging participants in the evaluation of analogical models in an effort to better understand how the periodic table is a model that represents the similarities and differences of the natural elements. The lesson aimed to garner understanding of the explanatory and predictive nature of the periodic table. Laurel and her team attempted to foster participants’ understanding of the connections between an atom’s atomic characteristics, which are unobservable entities, with natural observable phenomena. They began by using several analogical models that engaged students in establishing a protocol for sorting. They then connected these “pre” activities to an element card sort. Cards with information about an element were provided to the participants and they practiced sorting them into sensible groups and orders. The goal here was to generate understanding about how the periodic table was arranged based on these characteristics.

During her classroom observation, the lesson focused on students generating diagrammatic models of how and why materials move through a semipermeable membrane. The lesson began in the style of a predict-observe-explain activity. An egg, used as a model cell, was placed in a series of solutions over the course of five days. Over the five days, the egg changed in a variety of measurable ways including gaining mass, losing mass, changing in shape, and changing in density. Students were challenged with

the question, “How can we explain the changes we are seeing in the egg?”. This lesson was explicitly connected to the big ideas of osmosis, diffusion, and concentration gradients.

**Attending to students’ ideas (Score = 4).** In the pre-institute lesson, Laurel often asked very simple questions that required students to provide one-word answers. She quickly responded to most of these answers with a simple “yes” or “no”. The classroom discourse observed in this lesson did not go beyond the IRE pattern.

During the institute lesson, Laurel and her group members were actively experimenting with the questioning strategies discussed in the institute. These strategies were focused on eliciting students’ ideas and building on those ideas throughout the lesson. Although Laurel struggled at times to make the next move, she was overtly trying to do so. This was also evident to the participants who commented during the lesson debriefing. Participants recognized that Laurel was listening to the initial ideas that participants posed which represented their prior knowledge. She often referred back to the prior knowledge and built on those understandings. For example, at one point a participant was referring to a characteristic of an element as being “stronger”. Laurel replied by saying, “Stronger, I like that, what do you mean by stronger?” After hearing the response from the participant Laurel stated, “Let’s remember that word”. This exchange signifies Laurel’s progress in attending to students’ ideas.

Over the course of the five day in-class observation, I observed Laurel engaging her students in several iterative cycles of making observations, identifying patterns in data, proposing tentative models, collecting data to support or refute those models, and

modifying the models based on what they had learned. She used a lesson that was developed to foster student thinking and model development. Students then used the model they developed to explain and predict the behavior of semi-permeable membranes in living cells. It was the first time Laurel had attempted a lesson like this and after the second day of her implementation she was really struggling to connect all of the important aspects of lesson to the students' current but tentative understandings. During the debriefing session after the second day of the observation, Laurel asked if I could help her in the next class. So on day 3, when the students were discussing the patterns in their data, I facilitated a 10-minute whiteboard discussion using the types of questioning strategies that were introduced at the summer institute and fostered connections between the current ideas of the students and the science concepts being studied. After this short interjection on my part, Laurel was able to continue the lesson for the remaining 2 days of the week.

In our debrief on Day 3, Laurel was impressed by her students interactions with me and felt even more motivated to engage them in a similar way that I did during the board meeting. On day four of the observation, Laurel led a more successful whiteboard discussion than any of the previous days. During the debrief after this class period, we discussed further refinements to the discussion process and discussed potential sequences for the final whiteboard discussion that would happen on the last day of the lesson. By the end of the week, Laurel was leading effective “board meetings” by herself and considering next steps for students to apply the model they had generated to a new phenomenon.



**Choosing activity and framing intellectual work (Score = 2).** During the pre-institute lesson, Laurel was not engaging students in making predictions with the molecular models about molecular behavior or the relationship between the models and the characteristics of the molecules being modeled. In fact, there were no references to any connections to the Nature of Science, the discipline of chemistry, or any other epistemic aspect of science.

During the institute lesson, with its focus on understanding the periodic table as an explanatory model for the patterns in atomic properties, Laurel often referred to this work as a scientific process and as such, was leaving the explanations to the participants to develop. As more elements were included in the sorting activity, participants decisions changed based on the new evidence being added. During one of these conversations, Laurel stated, “this is just what scientists had to do when they were figuring this out”.

Laurel’s progress in this aspect of implementing model-based teaching advanced further during her classroom lesson. Her choice of a lesson that engaged students in the iterative generation of multiple models for a phenomenon demonstrated her growing understanding of the importance of authentic scientific investigations. Throughout the process, Laurel encouraged students to make predictions based on their current model. New predictions were required to be grounded in explanations that their current model could provide. When students’ models could not demonstrate the prediction being posed, she encouraged students to change their model to reflect their thinking before proceeding with their predictions. Throughout these instructional strategies, Laurel continued to refer to the models as the tools of science that are used to investigate unknown phenomena.

**Pressing for explanation (Score = 4).** In the pre-institute lesson, Laurel was not observed pressing students for any evidence based explanations. The lesson was facilitated primarily through an IRE style, with recall level questions, resulting in a discourse that left little room for student explanations. During the institute lesson, Laurel and her group members focused on requiring participants to use the evidence on the element cards to ground their explanations of the patterns they were seeing in the periodic table. Participants were encouraged to discuss their ideas and how they were based on the data.

In her classroom lesson, her decision to use an iterative cycle of model building, testing, and revising, supported her ability to engage students in generating evidence-based arguments. During the latter rounds of the investigation, Laurel was prompting students to record data that could be used to support, refute, or otherwise change their model they were working on. After each modeling revision session, students were required to share aspects of their model that had changed and to describe the evidence that led to that change. By the last day of the lesson, students were also required to describe their experiments in ways that drew on scientific ideas such as concentration gradients, kinetic molecular theory, and other big ideas in chemistry and biology. This progression from data based explanations to scientific explanations that draw on scientific theories and laws indicated Laurel had achieved a sophisticated level of ability in teaching students how to construct evidence based explanations as well as differentiating between data and evidence.

In summary, Laurel made the most gains in implementation of any of the participants at the summer institute. As she indicated in both her daily reflections and in

her interviews following the summer institute, Laurel was very motivated to incorporate model-based teaching into her instruction. She recognized how effective it could be in both her improving instruction and in student understanding.

### **Laurel’s Use of Questioning to Facilitate Modeling Discourse**

On a pre-institute survey, Laurel described herself as a “learning facilitator” and having a “student centered classroom”. She stated that she asks open-ended questions in order to get them to analyze what they are learning. She stated that students tend to like this questioning method of teaching but there are some [students] that “just like to be told”. In the pre-institute lesson video that she submitted, Laurel was relying primarily on a teacher centered, didactic approach. When asked how she maximizes student learning on the pre institute survey, Laurel lists a variety of activities including lecture, lab activities, demonstrations and videos.

The video of Laurel’s pre-institute lesson was analyzed using the EQUIP discourse analysis tool. Analysis using the EQUIP identified Laurel’s use of discourse as consistently at the level of 1, the lowest level, in all dimensions. Her questions were generally directed to the entire class during her presentation of the instructions for the lesson. Responses from students were generally one word answers and Laurel typically replied by saying, “right”, “no”, or not responding at all. Questions were typically about the process and the steps to follow and did not go beyond the remembering level. This pattern of discourse continued throughout the class period and followed the typical I-R-E pattern. Laurel did not ask any follow up questions when students did respond nor did she respond in any way to any student ideas voiced during the class period beyond saying

“yes” or “no”. Although Laurel has a vision of her teaching that includes asking open-ended, analytic questions, she was not observed utilizing this type of questioning in her recorded lesson.

Laurel became more confident in using effective questioning strategies as a result of attending the summer PD institute. In a response to a question on the third day of the institute about describing her own skills with questioning prior to the institute, Laurel stated that her skills were “terribly mediocre...I know how to get better now”. This statement was supported by her implementation during the lesson she and her group led during the last day of the summer institute. Laurel used several of the new questioning strategies she had been introduced to during the institute and was encouraged by the comments of the other participants after the lesson. In the daily reflection from the day of her implementation she said that learning about the new questioning strategies was the most meaningful activity of week and that she planned to “reorganize many of my already existing plans” to improve the use of questioning.

I was able to observe Laurel for a 5-day sequence of lessons in her AP Biology class as she implemented a model-based lesson in the school year immediately following the summer institute. Over those five days, Laurel’s use of questioning steadily improved as she practiced facilitating whole class discussions focused on the learning goals of the unit. Early in the week, on days one and two of the observation, Laurel’s questioning was similar to her progress at the summer institute. Her questions attempted to engage students in discussion. The discussion was still primarily controlled and directed by her but she did occasionally follow up student questions and responses with more probing questions. By the end of the five-day unit, she was consistently and effectively

facilitating discussions that were conversational and had fostered a classroom culture that supported students questioning and responding to one another. Upon analyzing the video of the final classroom observation using the EQUIP, Laurel had achieved scores in the proficient or exemplary levels for all five of dimensions of the EQUIP's Discourse Factors rubric.

### **Laurel's Growth Network**

Through identifying Laurel's growth network using the IMPG framework, I found that her growth was primarily emanating and occurring in the domain of practice and the domain of consequence. This was similar to Carla in that the changes that were occurring were more related to their practice and to students than to their own personal domain. In the following section, I will outline the growth sequences that make up Laurel's growth network.

Laurel's experiences at the summer modeling institute had a large impact on her understanding of models and scientific modeling but also had a large impact on her views of teaching and learning. In a post institute interview, I asked Laurel if she ever taught specifically about what a model was or how they were used and she stated,

No, definitely not. I don't know why. I probably should have been but it wasn't in the standards. I never...it was never clear or never...I don't know. I don't know why I didn't. I don't have a really good reason. I know different now but that's what I interpreted a model as. It was something that represented something [like] a mass that they couldn't see like an atom or something...

When I probed for her to explain what has changed now in her view of models and their use in the classroom Laurel stated,

It's a lot broader. A model doesn't necessarily have to be an object or a piece of lab equipment which is really what I thought it was before. It can be a picture that a kid draws that's showing me what their understanding is of something that either I've taught or I haven't taught yet. It can be a process. It doesn't need to be just through lab equipment.

This conversation identifies how Laurel believes the institute has changed her view of models and scientific modeling. Her participation in the Institute led to improvements in all three dimensions of knowledge of models and modeling which was evident on her post institute KSM survey responses and in the post institute interview. She gained a more informed understanding of the nature of models, how scientific modeling is connected to the work of scientists, and how the process could be used in the classroom.

Laurel also recognizes how her change in views about models and modeling has led to her seeing the pedagogical benefits of teaching with and about models. Laurel recognized that using modeling in the classroom is an opportunity to increase the rigor in her classroom and push students to think more critically. She elaborated on the benefits of modeling stating that it allows for, “enabling students to construct their own knowledge more easily and as a teacher, differentiation becomes easier”. She also recognized the challenges associated with modeling, when she described the increased time it will take to plan lessons but she immediately followed this with the assertion that this time is not any more than any other form of quality planning.

Laurel's changing conception of models and the resulting recognition of the impact this will have on her teaching represent the first growth sequences in Laurel's growth network shown in Figure 5.3. The External Domain(ED), in this

case the summer professional development institute caused Laurel to reflect on her own knowledge and subsequently on her own practice. The numbers 1 and 2 in Figure 5.3 denote this sequence of reflections.

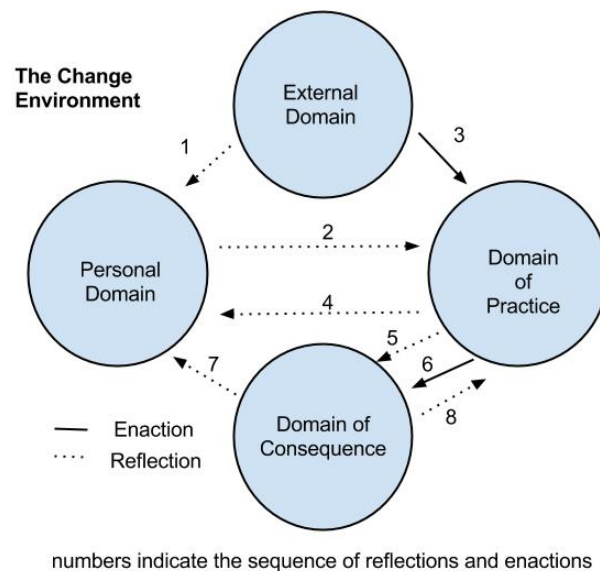


Figure 5.3 Laurel's growth network.

Laurel was an active and enthusiastic participant throughout the week-long summer professional development institute. Based on her requests to learn more about the physical science content, she was assigned to the chemistry group with her approval. On day 4 of the institute, the teachers were able to practice teach some of the lessons they had co-constructed with their peers at the institute during the previous two days. Working with another teacher at the institute, Laurel's modeling lesson designed during the institute began with an explicit introduction to the concept of a model and why we use

models, both in science and in the classroom. The purposes of models she indicated were for explaining trends or to see them more easily as well as helping to understand the topic students are learning about. She began by posing questions like, “What types of models have we used? Why do we use models?” This is an example of how Laurel attempted to go beyond the use of a model as just a representation and engage students in explicit discussions about the use and the role of models.

After the discussion of models, Laurel’s institute modeling lesson engaged the participants in thinking about how they would categorize and sort a large pile of clothes shown in a picture on a PowerPoint slide. A second sorting activity was done with paint color cards. These sorting and categorization activities were intended to build a foundation for sorting element cards for the purpose of understanding how the periodic table is organized based on the trends in element properties. During her delivery of the lesson, Laurel was observed practicing the types of questioning strategies she had learned in the previous days of the institute. She also had an opportunity to practice a whiteboard meeting during the implementation of the lesson, which challenged her questioning skills most directly.

Laurel had designed and implemented a lesson based on what she had been learning during the institute. Her inclusion of an explicit discussion about models, engaging students in a modeling activity, and focusing on facilitating discourse through questioning, represents an enaction, emanating from the External Domain to her Domain of Practice. This is noted in Figure 5.3 with the number 3.



During the debrief of the lesson, participants at the institute were extremely positive and pointed out Laurel's use of scaffolding and questioning to support the lesson as especially well done and provided new ideas for their own practice. They also pointed out that the lesson could have gone further by engaging students in testing their models. Ideas were posed for how this could be done. Laurel was receptive to these ideas and seemed to be encouraged by the positive feedback she was receiving about the activity from the teachers. Teachers also commented about Laurel's use of scaffolds, her discourse moves, her attention to building on skills participant's already had, and relating the learning objective to their previous knowledge. The comments from the teachers are seen in her reflection from the day of this activity. Laurel found the practice lessons to be helpful because they "brought out issues that will come up". She learned that she would need to "be prepared for the unexpected". She states that she is interested in this style of teaching but recognizes that it will take work.

The enactment of her modeling lesson eventually leads Laurel to a clearer understanding of her own teaching practice, how students will benefit from this type of teaching, and how modeling can play a larger role in her teaching going forward. It was also an opportunity for her to reflect on how the institute's activities might play out in her classroom. This was evident in her statements on her daily reflection. On the electronic survey after the last day of the institute, Laurel commented that the "questioning activities and the modeling practice showed an area of weakness in my teaching practice." As such, the practice teaching experience instigated a reflection from the Domain of Practice on both her Personal Domain and the Domain of Consequence, noted by numbers 4 and 5 in Figure 5.3.

Throughout her daily reflections, the most salient experiences for her were the thoughts and ideas presented about discourse moves and facilitating student-to-student discourse through teacher questioning. On Day 3 of the institute, her daily reflection identifies the importance of the questioning techniques. Laurel writes, “the importance of the level of teacher questioning in using scientific modeling” had become apparent to her. Elaborating on the benefits of this pedagogy, she writes, “Enabling students to construct their own knowledge more easily and as a teacher, differentiation becomes easier”. She recognizes the importance of questioning and engaging students in using evidence to support claims and notes that she can reorganize many of her lessons to do this. These understandings about her own classroom represent a reflection from the Domain of Practice on the Domain of Consequence, noted in her growth network as number 5 in Figure 5.3. These reflections indicate she is making connections between scientific modeling and the impact it will have on her teaching and student learning in her classroom.

In an interview following the institute but before her modeling lesson, Laurel talked about one of the modeling activities that she did in her classroom following the institute. She states that she:

went through the whole thing where we drew the models, then we did an experiment, then we went back to the models, revised and predicted and the whole process. I really tried to get the students to come to a consensus.

This statement indicated that Laurel now has an accurate understanding of how the use of models is a scientific process and can foster learning in her classroom. When asked if she thought this lesson was a success she said:

with the modeling yes but with the content of the acid base buffer system no. I'm not real confident in my questioning yet. A real big part of teaching the models is the questioning. So, I generally use the models as a way to find misconceptions in things before we start talking about stuff.

Here she again expresses her challenges with questioning. She attributes her lack of ability to facilitate good questioning as the downfall of the lesson. Laurel is attempting to use the modeling in her own classroom. She has become familiar enough with the modeling cycle to enact it in her classroom but still recognizes that it falls short due to her own lack of skill with questioning strategies. It is evident that her use of questioning, not her knowledge of models and the process of modeling, is the primary barrier for her progress in implementing modeling in her classroom.

Based on her recognition of her own lack of ability with questioning, she now attempts to compensate for the lack of success with using questioning to facilitate the students coming to consensus by using animations of the process that they are trying to model. She stated that she explicitly referred to these animations as a consensus model. Her use of an animation as a scaffold and as a “work around” for her lack of questioning skills is a testament to her beliefs about the importance of using modeling in her classroom. Further evidence of this is her explicit insertion of lessons focused on models and modeling. Since the beginning of the year following the institute, Laurel added a day of talking about Scientific Models to the beginning of the year, right after talking about the scientific method. This addition of a day focused on models to her courses is similar to Andy's additional lesson on Scientific Models. However, Laurel describes with more detail how this is impacting students and their participation in her class. Andy did not elaborate on student reactions to this addition. Laurel talks about the students' reactions in the following comment:

They've never really learned in this way before. They've never been I guess challenged with critical thinking type questions or higher level questions in their previous courses. Or maybe they have and they weren't successful and they weren't taught on how to think through those kinds of questions. So when I challenge them with what do you think is happening and they're trying to think through it, it's been kind of, it's been difficult to get them to either try or to give them the confidence that it takes to actually draw their thinking on a board and risk being wrong. I've kind of wanted them to just think on their own without just being told things so that's why, that's what I mean by challenges.

This discussion about how she is enacting modeling in her classroom and its impact on her students represents the convergence of her new understanding of modeling and her growing abilities with facilitating classroom discourse through her questioning. When asked why she continues to try to implement modeling in her classroom despite the challenges she points to her recognition that, “students can help each other correct misconceptions because the process allows them to communicate with one another. This process, more so than others, really encourages that communication.”

When asked about students fixing their own misconceptions she elaborated by describing how she has begun to improve her probing questions saying:

Generally what happens is when we're talking about a model or we're talking about things we've created, whatever and I'm asking questions, I do... I really like the questions that you would model for us at the Institute...like...”So, can you explain what she just said?” Or, “Can you explain what he just said?” Or, “How is your model different or similar to their model?” When they're asked those questions, a lot of kids, they're like, “Oh, that's a little bit different,” or, “That's similar,” and you can hear them reasoning out, “Well maybe that's a better idea,” or, “This is a good idea,” and then they kind of go, “I see, I see. I see why they do that.” And now it makes sense, they go, “Oh.” And it's within a few seconds they clear up their misconception or they remember, “Oh yeah, we learned that in regular Bio,” “We learned that in Earth Science,” or whatever.

It seems that Laurel's persistence with modeling is driven by the feedback she is getting from her students as well as her own hopes for a student centered classroom. The

enactment of modeling lessons in her classroom is impacting her students in a variety of ways. In her pre-observation interview, Laurel reflected on how her students experiences with models in her own classroom were similar to the experiences of the teachers who attended the institute. She referred to the teachers as “all having advanced degrees and they didn’t even know what models were”. She connected the novice nature of the teachers with the novice nature of the students. This represents an enactment from her Domain of Practice on the Domain of Consequence, represented by number 6 in figure 5.3. The feedback she is getting from students is creating change in both her domain of practice and her personal domain. Student feedback is causing her to recognize changes she needs to make for future enactments in her classroom.

Student feedback is also providing her with new insights into her own teaching, which is represented by numbers 7 and 8 in Figure 5.3. She describes how “all students are benefiting from this strategy” and has begun to see herself enacting a student centered classroom as she described before the institute.

### **Classroom Observation**

For Laurel’s classroom observation, I was able to observe Laurel for five consecutive class periods. This was a great deal more time than I was able to spend in any of the other observations that I conducted. As a result, I was able to collect a richer data set from Laurel’s classroom and will describe her experiences in greater depth than the other cases. This increased time also provided the opportunity to co-teach with Laurel for a few minutes in order to demonstrate some of the more advanced techniques associated with facilitating Model-Based Teaching.

I observed the last class of the day, which was AP Biology. Each day in Laurel’s class, the class activities were recorded on video and Laurel and I met after each class period to discuss the activity and her thoughts about her implementation. Based on a preliminary review of the data I had collected before the scheduled observations of Laurel’s classroom, I had recognized that Laurel’s questioning was of interest to her and me. I was also interested in seeing if I could identify how NOS was influencing her implementation.

On the first day of my scheduled five-day observation, Laurel began by prompting the students that “this week was going to be a little different”. Laurel began a presentation about the Claim-Evidence-Reasoning strategy she planned to use as a framework for this modeling activity. The CER method was described and discussed at the summer institute and this was something that Laurel planned to use extensively over the next few days. Her opening statement indicated that her classroom and the instructional strategies she used rarely involved an inquiry approach to classroom instruction. She later explained that, although she would do many laboratory activities over the course of a year, and these lab activities were hands-on, they were mostly cookbook labs. As the class discussion began, Laurel’s reliance up to this point on the scientific method is evident in the dialogue below:

Laurel: When we do labs or do science experiments typically what do we start with?

Student: A purpose?

Laurel: A purpose, a question, a title—which sometimes implies a purpose or question

Student: objective

Laurel: What do we do from there?

Student(s): Form a hypothesis...

Laurel: We usually form a hypothesis; we come up with what we think is going to happen based on something we've learned, something we've studied, and something you already know. So this is similar to that kind of thinking, it's not that much different it's just got a different name, Claim - Evidence - Reasoning. It's basically coming up with what you think is going to happen on a given scenario, what evidence could you collect, then using the evidence to reason why your claim is correct or not correct. The reason this is important is because, "my mom said so" is not good enough for science.

This discussion and its use of CER as a "scientific method" illuminate how Laurels' view of the scientific method influences her presentation of a new pedagogy. She attempts to relate this very different way of doing things to what her and her students are already familiar with in her classroom.

Once the discussion about CER was complete, Laurel began to discuss the important role data plays in this process. So she began by asking, "What do we use data for?" She emphasized that we need data to use as evidence to support our claim. During this period of instruction, Laurel stated, "Up to this point I have told you what data to collect - in this activity you might need to think about your own data and what you will collect. I was sometimes vague before, I am going to be more vague with this activity." This statement was further indication that an inquiry approach to science instruction had not been the primary method of instruction for her classroom. She followed this statement with a number of questions for students. They were not open-ended but she seemed to be encouraging students to provide their input into the discussion. In doing this, Laurel seemed to be trying segue to a more inquiry-based method of teaching by encouraging the students to be comfortable with her vagueness and clearly stating expressing that it

was intentional. She then provided them with a brief overview/discussion of how to do some basic measurements and data collection (mass, volume, length, etc.).

Her instructional unit called, “The Eggsperiment”, began by instructing students to collect a few cursory data points about an egg and a vinegar solution; mass of the egg, volume of the liquid, and other qualitative observations of both the egg and the vinegar. After these data were recorded, the students submerged an egg in a vinegar solution for 24 hours. After the first 24 hours, students measured the mass of the egg, made observations about its size and other qualitative observations, then submerged the egg again but this time, in a different solution, salt water. This pattern of observation after changing the liquid, repeats over the next four days, moving the egg from the vinegar to salt water, corn syrup, and finally distilled water. Over the course of the five days, the egg gained and lost mass, the liquids volume and density changed, along with other qualitative changes. Over the course of the five days, the data related to the changing densities of the liquids and the changing mass of the egg were woven together and a model of osmosis and diffusion across a semipermeable membrane emerged.

Her questioning during this first lesson in the unit was rarely more than recall but on several exchanges with students she was probing their understanding and asking them to explain themselves and be explicit with their understanding. The following exchange shows how Laurel was certainly probing students but not feeling quite comfortable with the technique:

Student 1: Do our claims have to be the same?

Laurel: You can have different claims as long as the evidence you are collecting will support both claims. You see what I mean...if



he's....wait...let me think about that? So, let me hear your claim. What do you think is going to happen? You can disagree, that's definitely ok.

S1: The shell is going to start to crack.

Laurel: Ok, and you think...what did you tell me?

S2: The texture will be softer than what it is now and the color will change from white to more yellowish.

S1: Oh yeah and the color...

Laurel: So, can you guys come up with some evidence that will support both of your claims? I think your claims are fine. This is not a right and wrong thing. This is a thinking process. So, what evidence are you thinking, he's already told me his evidence, and what he's going to collect, is what you are going to collect going to interfere with what she is going to collect? I think it's cool that you disagree. I like to disagree...or maybe you're both right? So what is your evidence?

S1: What do you mean by evidence?

Laurel: So when you are trying to collect data or evidence it needs to support or refute what you claimed originally right?

S2: Isn't vinegar an acid?

Laurel: we don't know....this is a process of finding out. I could just tell you what is going to happen but that would be boring. How are you going to be able to prove to me that your claims were right or wrong?

During the debriefing session following the lesson on day 1, Laurel described how difficult it was to find the right questions that would guide the students' thinking without giving away the answer. She stated:

It went better than I thought it would, I feel like I was so focused on the questioning that I was forgetting the long term goal of the lab. I totally forgot about them needing to have the mass done. I've never done this lab this way before. I've always just told them what to collect...so...knowing that I should have told them...collect this, this, and this and then collect some of your own. Is that what I should have done?

This comment from Laurel indicated how the focus on questioning was so overwhelming that she had lost her focus on the goals for the lesson.

In addition to her apprehension about questioning without giving away too much, Laurel also had some preconceptions about her students that were impacting her lesson delivery:

This group is different than I've ever had before, they hate doing stuff like this, they don't like to think- they hate this - most of the time when you have truly gifted kids, there like "Yeah!" so it's been a process for me to ask the right questions to lead them, groups I have had before - I could ask them questions and they would take themselves there and they would have dialogue but this is a little bit difficult. I don't know how I am going to ask the right questions without telling them...

Laurel was struggling with several things here as indicated by the quote. She didn't seem to be ready to anticipate what students might ask or do because this was the first time she was trying this approach for this lab activity. She also indicated her focus on questioning and how that was taxing her to the point of forgetting the bigger picture of the lab and what understandings she was hoping to get from the students. During the debrief, Laurel and I discussed a possible sequence of questions for the next days discussion that would guide the students through the important ideas that the data should be raising.

During the lesson on Day 2, Laurel showed some improvement with her questioning but still missing some opportunities to engage students in thinking critically about the data they were finding. During the debrief following the lesson on Day 2 Laurel was feeling very frustrated, specifically about her questioning strategies. We considered the impact of me joining in these conversations the following day. Laurel agreed that this could be helpful, for her and her students.

During the course of the lesson on day 3, I engaged with students for about 10 minutes during a whiteboard discussion. I asked some very pointed questions about their

data and asked them to identify the possible connections between the different data. After the lesson, Laurel explained how she interpreted my interjection.

I really liked it, just so I could see because I was really apprehensive about the whole newness of everything. To actually see it done with my kids because that was the only time I've ever seen it done with kids. The types of questions you asked were great.

During the lesson on Day 4, Laurel was able to better facilitate these discussions and used several of the questioning strategies I had demonstrated the day before. She described her planning and implementation stating,

I spent time anticipating what their findings would be and I rehearsed it. I was asking them questions, it was natural ... it was easier than I thought. Especially K\_, she surprised me. She actually has some depth to her! [Her questions are] ... never kind of deep, maybe because I never press them. This is bad but I don't want them to be worried about being wrong... but today she was just explaining things, she was right too!

Day 5 of this lesson was vastly improved from the first day. Laurel facilitated the summative discussion of the entire lesson with skill. Students were responding with evidence-based statements about their reasoning and explaining the processes of diffusion and osmosis across a semi-permeable membrane incredibly well.

Laurel's progress was very different from both Andy and Carla. She was able to implement a cycle of modeling that exemplified most if not all of the characteristics of an adept form of Model Based Teaching. In an interview following the classroom observation, Laurel described her level of motivation to continue using Scientific Modeling in her classroom. She also offered to help with future PD institutes and professed that she has really "drank the cool aid". In the next chapter, I will compare and contrast these three cases and elaborate on the patterns of implementation in Model Based Teaching that were evident in these three cases.

## CHAPTER 6

### CROSS CASE ANALYSIS, DISCUSSION AND CONCLUSION

I employed a multiple case study approach to identify how Knowledge of Scientific Models (KSM), understanding the Nature of Science (NOS), and the ability to use questioning to facilitate Model-Based Teaching (MBT), influenced three teachers' ability to implement MBT. In this chapter, I will first describe the similarities and differences among the three cases with regard to the three characteristics described above. I will also describe the similarities and differences of each teacher's growth network as described by the Interconnected Model of Professional Growth (IMPG) (Clarke & Hollingsworth, 2002). I will then describe how I used these similarities and differences to generate a performance progression of Model-Based Teaching implementation. Limitations of this study and Implications for professional development providers will also be discussed.

#### **Knowledge of Scientific Models and Scientific Modeling**

In all three cases, each teacher possessed an uninformed level of KSM prior to attending the summer professional development institute. While they recognized that Scientific Models should be used in the classroom, they were doing so in unsophisticated ways. For example, in her pre-institute lesson video, Laurel described models as representations of unseen entities and used them as vehicles to explain a curricular topic,

molecular structure. She made no explicit differentiations between the models and the molecules nor did she connect the models to a purpose or identify them as a product of science more generally. These three teachers did not engage students in explicit discussions about the nature of the model itself nor about why one model might be more useful than another. Although they described using different types of models, the purpose of the model was to facilitate student understanding of a curricular topic. While these activities utilized the descriptive and explanatory abilities of models, these teachers were not using them in ways that were similar to how scientists might use models as investigatory or predictive tools.

While using the Interconnected Model for Professional Growth (IMPG) as an analysis tool, I determined that each of the three case study teacher's growth networks began with the professional development institute which was situated within the External Domain of Clarke and Hollingsworth's (2002) model. The PD instigated enactments and reflections on both the Personal Domain and the Domain of Practice for each teacher. While institute activities were intentionally structured to engage teachers in developing and enacting modeling lessons, these three teachers also enacted new lessons in their classrooms in the subsequent school year. The teachers reflected on these classroom enactments in different ways, but the fact that they did engage in developing model-based lessons indicates that participation in the model-based lesson development at the summer institute was effective in getting these teachers to consider scientific models in more explicit and sophisticated ways.

As a result of participating in the PD, each teacher's knowledge of scientific models improved. Their use of models in their classroom also became more frequent and

explicit discussions about the purpose of models and their role in science were being included in the introductory discussions that often take place at the beginning of a school year. For example, Andy began his school year by adding a lesson on models following his discussion of “The Scientific Method”, Carla was adapting elements of the modeling pedagogy throughout her teaching, and Laurel was persistently practicing her facilitation of whole class discussions using whiteboards on which students had drawn diagrammatic representations of their understanding. For these three teachers, scientific models had taken on a new importance as evident by the increased prominence of models in their teaching.

### **Use of Questioning to Facilitate Modeling Discourse**

There were more similarities than differences between each teacher’s growth in knowledge of scientific models over the course of this study. Both before and after the professional development institute, there were more differences between the three teachers use of questioning than similarities.. Through the process of identifying and describing these differences and analyzing each teacher’s growth using the IMPG, I began to recognize that Andy was quite different from both Carla and Laurel.

Andy’s use of questioning was embedded within a didactic, traditional style of teaching and primarily used a initiate-respond-evaluate cycle of discourse known as Triadic Dialogue (Lemke, 1990). During the practice teaching activities of the institute, Andy did attempt some of the more ambitious questioning strategies that were discussed and demonstrated as part of the institute. However, these strategies were not present during the classroom observations.

Carla was quite different from Andy with regard to questioning. Carla employed a variety of questioning strategies both before and after the summer institute. Her pre-institute video showed her asking open-ended questions and probing student responses. Some of her interactions could be described as an IRE pattern. Yet, open-ended questions and less evaluative responses were more evident in her classroom dialogue than in Andy's. In her post institute classroom observation, Carla rarely engaged in an IRE pattern. She had expanded her repertoire of questioning strategies to include the reflective toss and asked students to re-voice each other's ideas as she checked for understanding. She was visibly hesitant to evaluate student responses and she was making her efforts to be metacognitive explicit to her students.

Laurel was not quite as skilled with using questions to facilitate classroom discussions prior to the institute. She referred to the activities of the summer institute that focused on questioning and discourse as the most meaningful activities of the institute. She referred to her questioning abilities as a "hole in her teaching". During the practice lessons, Laurel made an effort to practice all of the strategies that had been discussed by the institute instructors. In a post institute interview, Laurel linked her efforts to improve her questioning skills to her intrinsic interest in maintaining a student centered classroom in which students were forced to think and make sense of the content.

While Laurel and Carla began at different levels of ability with regard to questioning, Laurel's persistent efforts to improve and Carla's adoption of new strategies into her repertoire differentiate them from Andy in a meaningful way. This is evident when looking at the patterns in their growth network identified by the IMPG analysis. Within Andy's growth network, the domain with the most enactions and reflections,

either originating or developing, is the Personal Domain. For Laurel and Carla, this is not the case. The enactions and reflections in Carla's growth network are primarily coming from the Domain of Practice. Laurel's are coming primarily from the Domain of Consequence. This indicates that Laurel and Carla are primarily concerned with classroom impact whereas Andy is more focused on his own learning and position in the classroom. Laurel and Carla's focus on student ideas and classroom practice were integral components of their implementation of MBT.

### **Understanding the Nature of Science**

In Part 1 of this study, each teacher's level of understanding of the Nature of science was determined through the use of two instruments, the VOSE and the VNOS-C. I determined that both Andy and Laurel possessed transitional levels of understanding the NOS while Carla was uninformed about the NOS. All three understood the tentative NOS and felt it was important to teach about this aspect of the NOS. They also felt it was important to teach about the structure of scientific knowledge as it relates to the relationships between hypotheses, theories, and laws. However, Andy was the only one of the three teachers who understood this relationship correctly.

All three teachers also supported the uninformed position that TSM is an important aspect of the NOS and believed that it should be taught to students. Andy was most influenced by TSM as evident by his "adding a day of models" to his discussion about TSM. His reflections during the summer institute he indicated that he wrestled with how to assimilate the modeling process with his views about TSM. Carla, while expressing support for TSM in her responses to the NOS instruments, was observed



straying from TSM during her lessons in which she was engaging students in scientific inquiry through model evaluation. While Andy and Carla both felt it was important to teach TSM, Laurel indicated she *strongly* supported the importance of teaching students TSM. Yet, as a result of her participation in the professional development institute, she recognized the pedagogical power of employing scientific modeling and was eager to get away from the cookbook lab activities most closely associated with TSM.

Figure 6.1 summarizes the patterns of similarities and differences among the three teachers in this study. All three teachers' knowledge of scientific models improved after attending the summer professional development institute. Carla and Laurel were similar in their attention to using questioning strategies that focused on student ideas whereas Andy remained mostly didactic in his approach to questioning. While Andy was the only teacher to fully understand the relationship between scientific theories and laws, his strict adherence to TSM was unlike Carla and Laurel's more flexible stand towards TSM. In fact, while Carla continued to employ strategies similar to TSM, Laurel was actively engaged in moving away from that structure and was doing so explicitly with her students.

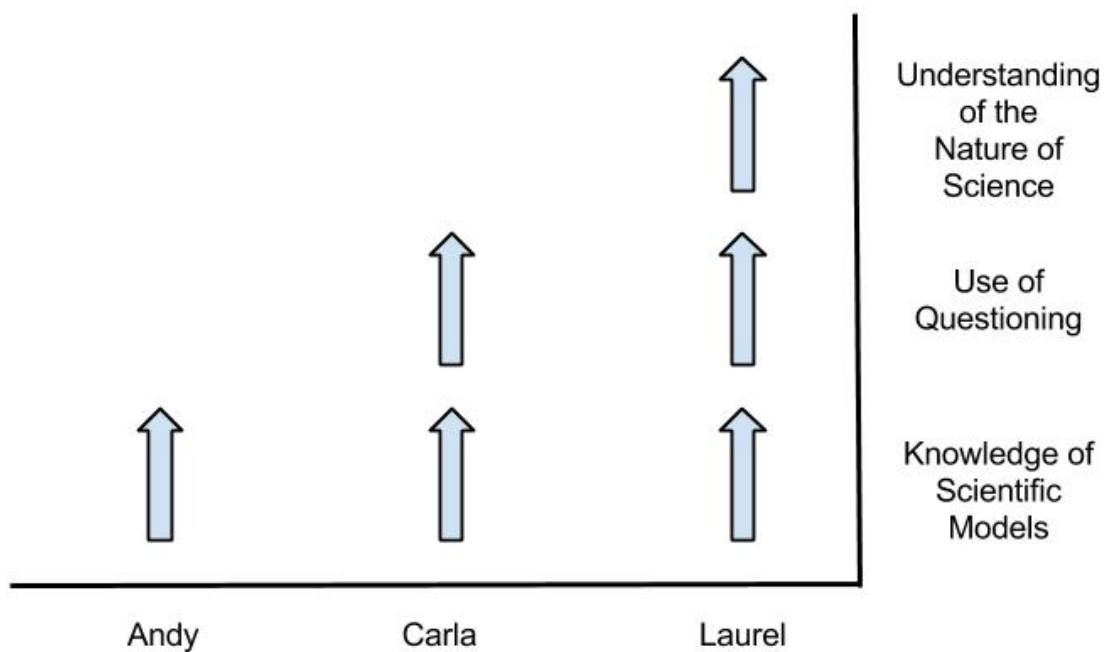


Figure 6.1 Emergent pattern of MBT implementation.

In summary, Knowledge of Scientific Models seems to be one basal factor to the progress of a teacher as they begin to implement model-based teaching. Questioning was indicated as a factor that plays a central role in the progression towards more proficient implementation, and understanding of the NOS is one critical factor for teachers attempting to help students understand how scientific modeling and scientific models are the process and product of science.

### Discussion

Model-Based Teaching (MBT) is one of the more difficult pedagogical strategies to employ in the secondary science classroom (Passmore, et al., 2010). Understanding how teachers develop the ability to implement such an ambitious pedagogical practice is

also difficult (Crawford & Cullin, 2004; Khan, 2011; Schwarz, Reiser, Archer, Kenyon, & Fortus, 2012; Thompson et al., 2009; Windschitl, 2004). Efforts have been made to develop learning progressions for Scientific Modeling for students (Schwarz et al., 2009) and for teachers attempting to implement model-based inquiry (Thompson, et al., 2009).

The cross case analysis in this study compared the patterns of similarities and differences in these three teachers' proficiency levels with regard to 1) Knowledge of Scientific Models (KSM), 2) the use of questioning to facilitate Model-Based Teaching (MBT), and 3) understanding of the Nature of Science (NOS) to the level of MBT implementation proficiency that each teacher was able to achieve. I found that each of these factors played a unique role at different times in the teachers' progression. These insights led to the development and articulation of a performance progression for MBT. In the section that follows, I will describe the four distinct levels of the MBT performance progression I have identified which included Pre-Modeling, Emergent Modeling, Transitional Modeling, and Adept Modeling. I will also describe how each factor examined in this study was found to play a mediating role in the progression from one level to the next.

### **Pre modeling**

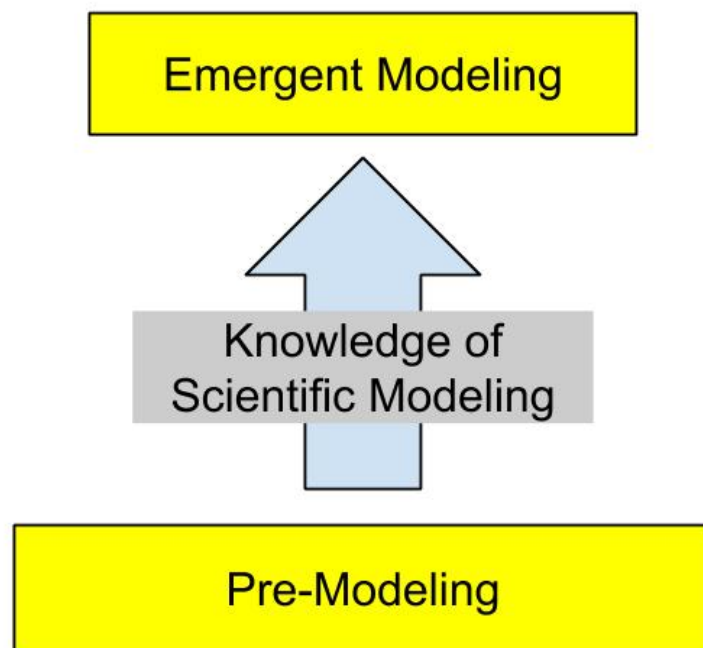
A typical high school science teacher possesses an uninformed view of the nature of Scientific Models and their role in the process of science (Justi & Gilbert, 2002b; Van Driel & Verloop, 1999a, 2002a). When a typical teacher uses Scientific Models in their classroom, they are most often used solely for communicating or demonstrating the curricular concept that is to be learned by students (Van Driel & Verloop, 1999b).

Teachers typically view Scientific Models as replicas, or as representations of things that are either too small or too big to view directly (Justi & Gilbert, 2002b; Van Driel & Verloop, 1999a, 2002a) and this is similar to the level of understanding of most students (Crawford & Cullin, 2004; Van Driel & Verloop, 1999b). The three case study teachers selected for cross case analysis in this study possessed a typical, uninformed level of knowledge of Scientific Models and Scientific Modeling prior to attending the summer professional development institute. Examples of this level of understanding from my participants included descriptions of models as tools that “make the abstract concrete” or as “a representation of some natural phenomenon that is too large or too small to study directly”. For the sake of organizing my findings, I have chosen to classify the unsophisticated, naïve level of modeling described by the literature and identified in my data as a “Pre-Modeling” level of proficiency. Prior to attending the summer professional development institute, all three of the teachers selected for this cross case analysis demonstrated teaching at the Pre-Modeling level of proficiency.

The types of discourse, questioning in particular, in a typical Pre-Modeling classroom is often didactic and centered on the teacher’s voice. However, one teacher’s proficiency with questioning may be very different from another teacher’s level of proficiency. Proficiency with use of questioning did not prevent teachers from advancing in their implementation of MBT until later in the progression. Questioning does play an important role in a teacher’s progression towards proficient implementation of MBT but not until they have begun to explicitly talk about scientific models and modeling. Similarly, levels of understanding of the Nature of Science (NOS) also varied at the Pre-Modeling level. While understanding of the NOS was found to be an important factor

later in the progression of implementation, it played a minimal role in a teacher's progression from a Pre-Modeling level.

After attending the summer professional development institute, each of the three teachers in this study showed improvement in their level of Knowledge of Scientific Models (KSM). With an improved level of KSM, all three teachers began to explicitly discuss models in their classroom, more so than before attending the institute. While each of the three teachers in this study progressed to a different level of proficiency with MBT over the course of the study, their progression began when the teachers improved their own KSM and began to explicitly discuss models with their students.



*Figure 6.2* KSM as the mediating factor in the progress from a pre-modeling level to an emergent-modeling level

Due to the variation in the use of questioning and in the knowledge of the NOS among these three teachers, I have concluded that an important difference between a Pre-Modeling level and the next level of proficiency in MBT is the teacher's level of KSM and their willingness to share this knowledge with their students. Once the three teachers in this cross case study had gained more knowledge about Scientific Models, explicit discussions about models and the modeling process began to emerge in their classroom practice. The teachers began to describe models and modeling as an alternative representation of the Processes of Science and began to talk about modeling in addition to their discussion of TSM. As such, KSM was an important factor for teachers as they began to implement MBT. Teachers who are more informed about models are likely to explicitly discuss models in the classroom and use the pedagogical strategies associated with Scientific Modeling. Shown in Figure 6.2, I have designated this level of modeling implementation as the "Emergent Modeling" level and have identified KSM as an important mediating factor in this portion of the progression.

### **Emergent Modeling**

Gains in KSM were similar across the three cases chosen for cross case analysis over the course of this study. After gaining knowledge of the nature and use of scientific models and the modeling process, teachers began to (a) explicitly discuss models with students, (b) engage students in building and critiquing models, and (c) reconsider their own understanding of the processes of science, specifically, "the scientific method" (TSM). These changes in teachers' classroom practice represented the initial steps in the implementation of MBT and are the primary characteristics of the next level of implementation, the "Emergent Modeling" level of proficiency.

At an Emergent Modeling level, teachers attempt to facilitate student learning of curricular concepts through the use and discussion of scientific models. At this level, teachers discuss the purpose for each model they use in the classroom with students but these purposes are typically limited in scope. The purposes of models described by Emergent Modeling teachers are generally limited to being a descriptive or communicative tool and not yet considered as predictive or investigative tools that are used by scientists. However, the purpose is at least connected to how the model is displayed or was generated. Teachers may also present the model as distinct and separate from the target being modeled but do not fully engage students in discussion of this aspect of the nature of models until later in the progression. Models are not typically described as a set of ideas that explain some phenomenon in the real world and as a result the nature of scientific models is not fully discussed.

Teachers in an Emergent Modeling classroom often engage students in working with diagrammatic models from a textbook, physical models, or simulations and animations. During these interactions with models, teachers explicitly differentiate between the model and the target phenomenon as they discuss the purpose of the model. Teachers may do this in a variety of ways ranging from direct instruction, presenting and discussing different models for the same phenomenon, engaging students in critically analyzing a model, or using a provided model to make inferences about other phenomena. During an Emergent Modeling lesson, teachers may also engage students in generating a model themselves. This is most often done as a formative assessment activity. In other words, the purpose of building a model is for students to share their current understanding or representing a phenomenon that is already understood. The

models are not recognized as predictive tools or as a set of ideas that can explain how or why a phenomenon occurs. For example, when Andy, whose classroom observation was noted as a case of Emergent Modeling, used the black box activity to engage students in the generation of a model, the model was a replica with no predictive or explanatory power. While this activity can be implemented in a way that makes clear connections to the NOS and to the nature of models, Andy's delivery of the lesson did not emphasize these aspects of the modeling process. At the Emergent Modeling level, the connections between Scientific Models and the NOS are typically surface level connections or inconsistent with an informed understanding of the NOS, if the connections are attempted at all. For example, teachers may still adhere to TSM as the process of science and attempt to present their modeling activities to students in ways that are compatible with TSM.

Teachers who are recent participants in model-based professional development often use elements of modeling pedagogy, such as engaging students in drawing a model on a whiteboard, superficially. This has been referred to using the terms bricolage or "tinkering" (Huberman, 1993,1995). These uses constitute superficial imitations of new practices, without disrupting the current cultural norms of the classroom (Windschitl, Thompson, et al., 2008). These superficial types of enactments are the hallmark of the Emergent Modeling level of implementation.

### **Transitional Modeling**

While all three of the case study teachers had demonstrated the characteristics of an Emergent Modeling level of proficiency, further progression depended on their use of



questioning to elicit and build on student understanding of Scientific Models as more than just descriptive representations. For example, Carla used questioning quite proficiently prior to attending the institute and the questioning strategies discussed at the institute were easy for her to incorporate into her practice. As a result, Carla was able to engage her students in discussions about the purpose of models and to critically analyze a model as it compared to other models. These types of conversations, facilitated by questions that elicited student's ideas in order for them to be discussed, goes beyond the conversations common at the Emergent Modeling level.

Carla was already using some of these questioning strategies in her practice and the explicit discussions about them at the summer institute supported her use of them. Similarly to Carla, Laurel demonstrated her beliefs in the importance of questioning to elicit and build on student ideas. While Laurel recognized early in the PD institute how her level of questioning needed to improve, it became more evident to her as she began to practice implementing MBT in her classroom. She identified her main challenge to MBT as a lack of confidence in her classroom questioning skills. She described how after each successive attempt at implementation, her questioning skills improved. After implementing several modeling lessons, Laurel stated,

...one [lesson] where I actually went through the whole thing where we drew the models, then we did an experiment, and then we went back to the models, revised and predicted and the whole process, I was able to see certain things they didn't understand. ...I think if my questioning techniques were better and I think if I had more experience that I can be more effective with giving models more often. So I really think, that's one of those things that are just going to come with practice.

Her dedication to practicing the questioning techniques introduced to her at the summer institute was evident during her classroom observation. Laurel had greatly

improved her questioning compared to her pre-institute lesson, which included questioning but was limited to an Initiate-Respond-Evaluate (IRE) model of dialogue (Lemke, 1990). During her classroom observation, Laurel asked multiple open-ended questions and employed techniques such as the reflective toss (Minstrell & van Zee, 2003), which she learned during the institute.

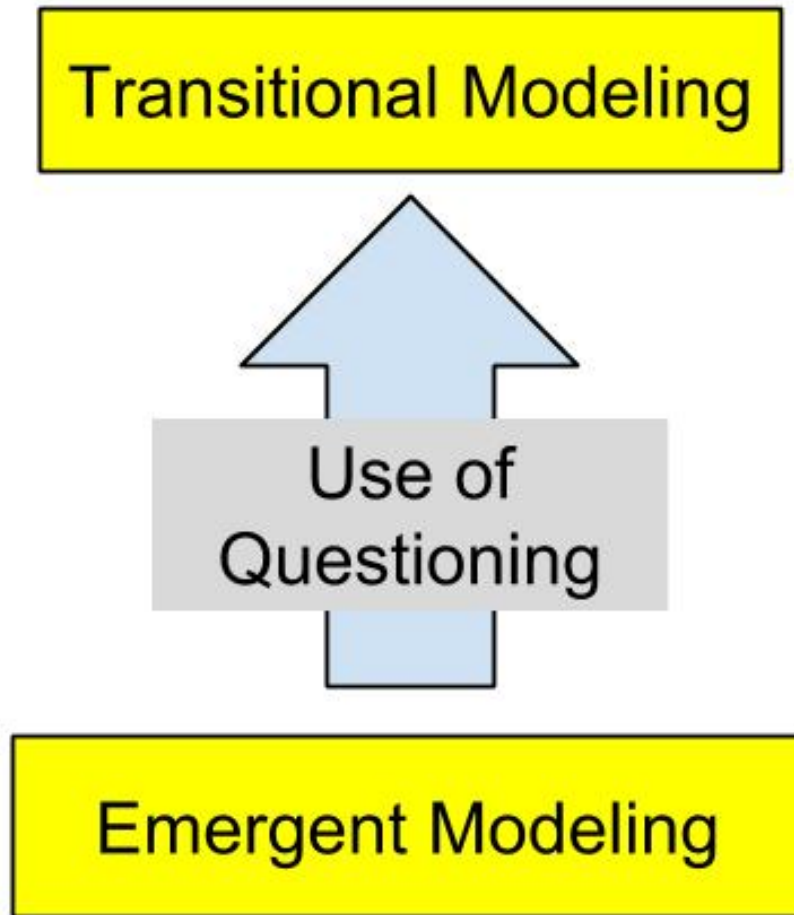
During one of the observed lessons, Laurel noticed that one of her students, typically not comfortable answering open ended questions, began to participate more fully in the class activities. Laurel noticed that other students, who had been similarly reticent, began to participate more as well. In one post-lesson interview, Laurel stated, “and so when they [the students] saw that [the quiet student participate], it was kind of, it was like a domino effect. It was really cool.” Laurel began to experience successes as a result of her continued efforts to improve her questioning which further reinforced her appreciation for MBT.

In contrast, Andy’s inability or unwillingness to change his didactic, teacher-centered style of instruction impeded his ability to engage students in discussions about the development of models as sets of ideas that explain underlying mechanisms of a phenomenon or their use as investigatory tools. Since these discussions were not taking place, students were not involved in critiquing a model or developing a model that was more than a replica. Carla and Laurel’s focus on student learning as indicated by the IMPG analysis supported their progress beyond an Emergent Modeling level of implementation of MBT.

In order for students to engage in the sense making processes associated with constructing an explanatory model, a teacher needs to be able to elicit student ideas through questioning rather than delivering the ideas via lecture or other limited forms of classroom discourse such as an IRE dialogue. Using questions to facilitate students understanding of their own models and the phenomenon being studied is important in that it helps students generate their own knowledge in a way that is similar to how knowledge is generated by scientists. In other words, the ideas on which the models are based are shared and discussed in a way that they can be linked together into an explanatory framework. Teachers who do not use questions that elicit and connect student ideas are less able to engage students in this sense making aspect of MBT. Therefore, teachers, who use questioning to elicit and build on student ideas, are better able to implement MBT in their own classroom.

Although Carla and Laurel began at very different levels of ability to use questioning in their classrooms, they both continued to progress in their questioning ability and as a result, were able to progress beyond the Emergent Modeling level in the lessons that were observed. While Andy's lessons were limited to an Emergent Modeling level, indicated by his more superficial adoption of modeling activities, Carla and Laurel's instruction began to make a transition towards a more proficient level of implementation through questioning that elicited student ideas in order for them to be discussed. I have chosen to categorize this level of progression beyond the Emergent Modeling level as the "Transitional Modeling" level. The Transitional Modeling level is mediated by a teacher's ability to engage in effective questioning that elicits and builds

on student ideas rather than further disseminating information. This is shown as the next level in the implementation progression in Figure 6.3.



*Figure 6.3* Use of questioning as the mediating factor in the progress from emergent modeling to transitional modeling.

In a Transitional Modeling classroom, teachers extend the explicit discussions about models that are present in the Emergent Modeling classroom. During Transitional Modeling, teachers engage students in learning curricular concepts through discussions that include the nature of models and the ideas on which those models are based.

Teachers at the Transitional Modeling level continue to encourage students to understand

how to differentiate between models and their target and develop an understanding of the role of models and modeling in science. This deeper and more focused attention on models as tools for doing science is facilitated by the use of questions to probe and extend student thinking.

At the Transitional Modeling level, model building is done in order to support the learning of a curricular concept but the concept is not the only goal of the model construction. Transitional Modeling goes beyond the curricular topic to include explicit discussion of the process of model building and how it is a scientific process used by many scientists, a connection to the Nature of Science (NOS). Engaging students in generating a model for a given phenomenon raises the cognitive load for students and facilitates deeper discussions of the role and purpose of models while enabling additional discussion points focused on the qualities of scientific models such as being empirical, theoretical, and predictive (Van Der Valk, et al., 2007).

While Carla, whose teaching was noted to be at the Transitional Modeling level, engaged students in building models, the models were not based on student ideas that would lead to the development of an explanatory model of some phenomenon that is not fully understood by the student. This would represent a more proficient level of MBT. At the Transitional Modeling level, students understand that the model is descriptive as well as explanatory, answering the “how” questions but they may not connect it to more theoretical constructs or engage with “why” questions. Where students in an Emergent Modeling classroom may explicitly discuss the role and nature of a specific model for a specific phenomenon, a student in a Transitional Modeling classroom would go further to describe how models represent the process and product of science in general. Discussions

may lead to generalizable statements about the nature of models beyond the current specific model being discussed.

Teachers in a Transitional Modeling classroom are familiar with models as both a product of science and a process used by scientists. They attempt to engage students in constructing, evaluating, or modifying models but these activities are not yet linked together into a coherent process that is explicitly explained to students. Teachers are employing more sophisticated strategies that engage students in critical thinking and analysis of models but still do not achieve a level of modeling that closely approximates processes associated with Scientific Modeling.

### **Adept Modeling**

At this point in the progression, Laurel and Carla were both using questioning to elicit and build on student ideas through conversations about models. They were also engaging students in building and critiquing models that are linked to curricular concepts in their respective courses. But Laurel was doing this in a different way. Laurel engaged students in model building activities that led to students gaining a deeper understanding of the underlying mechanisms of a phenomenon through a cyclic pattern of model building, predicting, experimenting, and model revision. In doing this, she engaged her students in processes that more authentically resembled the processes of science. In this way, her level of understanding of the NOS supported her ability to present the modeling process as an authentic scientific process. While at a Transitional Modeling level, Carla attempted a cyclic pattern of modeling but it was limited to building, critiquing and revising models of established knowledge presented through the use of a textbook. In

other words, Carla's students were generating models of phenomena that were already understood, more or less. The purpose of the modeling was not investigatory. The modeling was focused on generating new representations that were better able to explain the topic of focus.

While Carla's views of the NOS were considered transitional by the instruments I used in this study, she was also naïve in many ways. She adheres to a view of science in which truth can be discovered and believes that this is similar to religion. This was evident in her modeling implementation in that she was engaging students in the discovery of known concepts in a textbook. Carla is fairly good at using questioning in her classroom but she lacks the level of understanding of the NOS that would be needed to see modeling in a way that is required for more adept modeling. Laurel's understanding of NOS was mostly informed but with a few inconsistencies that restrained her to a transitional level of understanding as indicated by the instruments used in this study. In other words, Carla was at the lower end of the transitional level while Laurel was at the higher end of the transitional level. Laurel's students were generating models that communicated what they understood about a phenomenon that they were investigating. Further investigation was revealing inaccuracies in their models and led students to revise or modify their explanatory models as they gained new information.

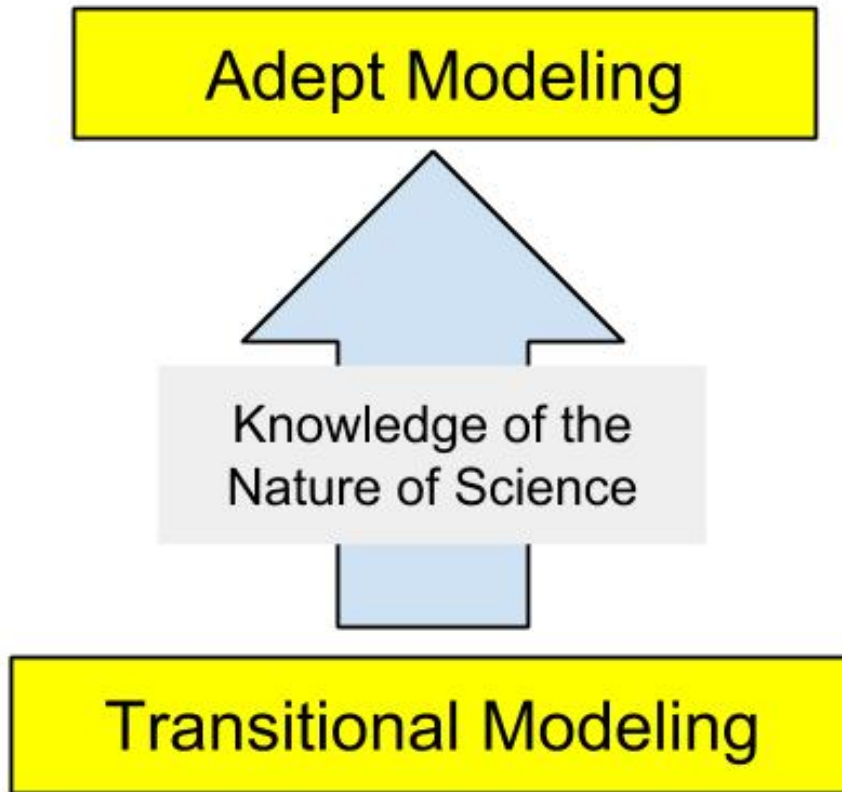
Engaging students in building models to be used as investigatory tools as well as explanatory tools in order to either predict or explain phenomena is an advanced level of MBT. This level of sophistication in the use of models is described by Schwartz and others (2009) in their student learning progression as a performance level 3. On a performance scale of 1 to 4 with 4 being the highest level of student performance,

performance level 3 occurs when “students construct and use multiple models to explain and predict aspects of a group of related phenomena”. I have chosen to designate instances when teachers engage students in modeling like this, as an indication of an Adept Modeling level.

While Laurel’s implementation was certainly not perfect, the important aspects of the model building process used by scientists were evident and her focus was on facilitating students understanding of the causal mechanisms underlying the phenomenon they were studying. Laurel’s understanding of multiple aspects of the NOS supported her ability to focus on investigating the underlying mechanisms of a phenomenon with her students. As such, knowledge of the NOS was found to be an important mediating factor in the progression from a transitional level of modeling to an adept level of modeling.

This is shown in Figure 6.4.





*Figure 6.4* Knowledge of the NOS as the mediating factor in the progress from transitional modeling to adept modeling.

When a teacher implements MBT in ways that present modeling as an authentic scientific practice, it is possible for students to come to deeper understandings of the NOS. A teacher's level of understanding of the NOS directly impacts their ability to facilitate students making explicit connections to the NOS. Based on these patterns, I have designated the "Adept Modeling" level as the highest level in the progression. While teachers who are adept may still be improving their implementation, multiple elements of authentic scientific practice are now evident in the MBT and their practice supports students' in making connections to the NOS.

Table 6.1 summarizes the major characteristics of each level in the Modeling Progression.

Table 6.1

*Characteristics of Each Level in the Modeling Progression*

<p>Characteristics of the Pre-Modeling Level</p> <p>Little or no use of scientific models in the classroom          Little or no discussion of models and their role in science          Limited use of effective classroom discourse          Limited or no explicit connections to the Nature of Science (TSM is the typical representation of science)</p>
<p>Characteristics of the Emergent Modeling Level</p> <p>Explicit discussion of the role and purpose of Scientific Models in Science          Students engaged in making their own models          Limited use of effective classroom discourse          Limited or no explicit connections to the Nature of Science (TSM is the typical representation of science)</p>
<p>Characteristics of the Transitional Modeling Level</p> <p>Explicit discussion, development, and evaluation of explanatory Scientific Models in the classroom          Classroom discourse is focused on student ideas and facilitated through effective questioning          Limited connections to the Nature of Science (Beyond TSM)</p>
<p>Characteristics of the Adept Modeling Level</p> <p>Explicit discussion, development, evaluation, and modification of explanatory Scientific Models          Students engage in iterative cycles of model development, testing, and modification          Classroom discourse is focused on student ideas and facilitated through effective questioning          Explicit connections to the Nature of Science (Beyond TSM)</p>

## Implications

This study showed that Knowledge of Scientific Models and modeling (KSM) is an important first step in Model-Based Teaching (MBT). This indicates that professional development programs that intend to develop teachers' ability to implement MBT should focus on building a strong knowledge base of Scientific Models and the process of modeling. Teachers should be engaged in learning through the development, evaluation, and refinement of their own conceptual models. For many of the teachers in this study, engaging in Scientific Modeling and deepening their understanding of the nature of Scientific Models and their role in science led to a new appreciation for the importance of engaging students in explicit discussion about Models in their classrooms. Teachers who did not experience this change in views about the importance of Modeling cited student deficits and institutional challenges like high stakes testing and classroom management as the primary barriers to MBT. In light of these findings, professional development providers should provide experiences for teachers that demonstrate how students perceived as "low achievers" can succeed in learning through MBT as well as provide instructional strategies that can adapt MBT to a variety of instructional contexts.

This study also showed that teacher questioning is a central skill in implementing MBT. The statistical analysis from part one of this study identified a significant association between a teacher's use of questioning and their implementation of model-based teaching. This finding was further supported with evidence in the cross case analysis. This makes sense in light of the important role questioning plays in scientific discourse. In both science and science education, questions are used to clarify and challenge claims and evidence and generate next steps in scientific inquiry.

As such, professional development programs focused on MBT should include a robust plan for developing teachers' ability to facilitate classroom discourse through questioning. Developing teachers' ability to use questions effectively through professional development requires providing teachers with specific strategies that facilitate their attending to student thinking (Harris, et al., 2011). Strategies such as collaborative video analysis or practice teaching should be a part of professional development efforts aimed at improving teacher's use of questioning. One potentially effective framework for supporting the development of questioning proficiency that supports classroom discussions would be the "The 5 Practices" developed by Stein, Engle, Smith, and Hughes (2008). The 5 Practices include, anticipating student responses to a cognitively demanding task, monitoring students responses to the task, purposefully selecting particular students to present their reasoning, and supporting students in making connections between the different student responses. Of particular importance to MBT would be the practices of anticipating and connecting. The practice of anticipating requires focused effort on question design during lesson planning. This includes anticipating student responses to those questions. Engaging in this practice would support teachers' use of questions that maintained focus on the underlying mechanisms of the phenomenon being studied and thus support teachers in the Emergent Modeling level of implementation of MBT. It was the Emergent Modeling level of MBT in which teachers were beginning to explicitly discuss and use scientific models. Their next steps in progressing were dependent on their use of questioning to facilitate the discussions required of the modeling process. Further supporting the classroom discourse that occurs during a cycle of modeling would be the practice of connecting. Connecting involves

connecting student ideas in ways that promote learning for all students in the classroom. The decisions a teacher makes in ordering and connecting student ideas from a variety of models can impact their ability to use the most effective questions at the most effective times. The integration of the five practices and PD focused on model-based teaching would be an interesting course for future research in this area.

An additional finding of this study was that the adherence to “the scientific method” (TSM) as a universal description of the processes of science impedes a teacher’s ability to facilitate MBT. Based on this finding, professional development programs focused on MBT should directly address the limitations of TSM and provide multiple examples of science being done that cannot be fully described by TSM. Engaging in activities that break down the importance of TSM could make the adoption of MBT more attainable, more quickly, for more teachers.

In order to determine a person’s level of knowledge of the Nature of Science (NOS), evaluation instruments should include items that determine the teacher’s level of knowledge of Scientific Models. If the scientific practices outlined in the new Framework and Next Generation Science Standards are really important to students gaining knowledge of the Nature of Science, then evaluation instruments should directly assess how teacher’s understand the connections between the practices and the NOS. In this study, I developed an instrument, the Knowledge of Scientific Models (KSM) questionnaire that attempted to identify teachers’ understanding of the nature of models. Since the current NOS evaluation instruments are not determining KSM specifically, I needed to develop the KSM questionnaire. Future iterations of NOS instruments should include questions from the KSM questionnaire such as, “What is a scientific model?” An

instrument that integrated these purposes would be beneficial to the science education community interested in promoting the use of MBT in science education.

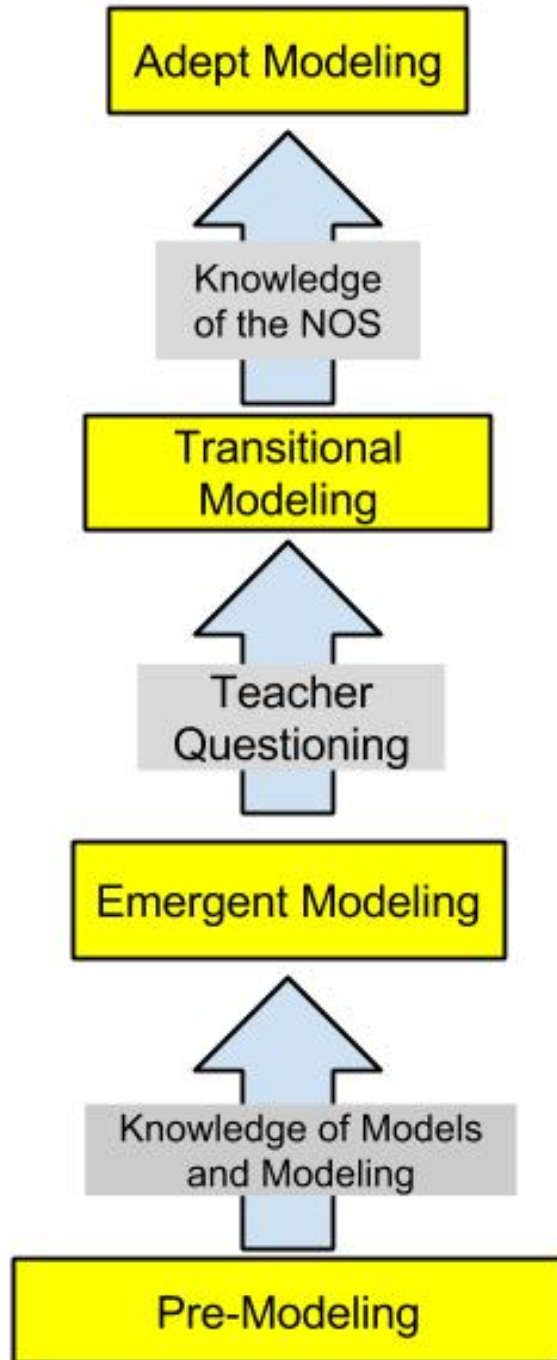


Figure 6.5 Modeling implementation trajectory.

Another finding of this study was that learning to implement model-based teaching takes time and persistent practice. While in-class support following a professional development institute was found to be effective in this study, it is not always feasible. PD providers should consider alternatives such as classroom video sharing or facilitation of an online professional learning community (PLC) as an additional support for teachers beginning to implement Model-Based Teaching.

The identification of a performance progression for MBT suggests how professional development can be differentiated based on the location of a teacher along the progression. PD providers should identify where teachers are along this progression prior to the start of the professional development program. This would allow for differentiation of the activities based on the location of the teacher. While PD should include explicit focus on the three factors identified in the progression, identifying where teachers are in the progression affords an opportunity to provide additional support for specific topics for specific teachers

### **Limitations**

One limitation of this study is the small population of teachers that participated in the professional development, which limited the number of case study teachers from which a purposeful sample could be drawn. The small number of participants also limited the type of quantitative analysis that was able to be conducted. Although generalizability is not the focus of qualitative research (Merriam, 1998), broader generalizations may not be possible from this study. Additionally, the teachers were only observed a limited number of times. Further testing of the modeling progression will need to be done to see

if the progression holds true over multiple teachers over longer periods of time. It may be that the model that was developed through this research represents a starting point from which future research into MBT might begin.

An additional limitation to this study was the use of researcher created surveys needed to identify the factors of focus for this study. The KSM questionnaire should be further validated by larger studies aimed at articulating teachers' understanding of Scientific Models and Modeling.

Another limitation of this study was the participants were voluntary participants in the PD program. Should school districts or teacher education programs draw on the findings of this research, teachers who are compelled to enact MBT may face different challenges earlier in the progression. The three case study teachers selected for this study were also more or less able to decide how to teach the content of their respective courses. In some districts and schools, mandated pacing guides and teaching strategies may not allow for MBT. In these cases, challenges to teaching MBT may be very different than those identified in this study.

### **Future Research**

The focus of this study was on three factors that impact Model-Based Teaching. As a result of the identification of questioning being a central and pivotal practice, more research should be done into how questioning should be supported for teachers implementing MBT. The importance of questioning to other ambitious pedagogical practices is suggested by this study but further focused research would be needed in order to make these conclusions. The potentially large and positive impact of providing



professional development through a robust framework of teacher questioning is indicated by this study but was not fully investigated.

While this study has outlined how three discrete factors impact a teachers' progression towards effective implementation of Model Based Teaching, there are other factors that should be considered in future research. For example, providing teachers with curriculum materials and guidance with modifying those materials to fit their own context, or providing guidance and support in developing their own curricular materials should be considered an additional important factor. Engaging in the implementation, modification, or development of curricular materials provides access for teachers whose progress with implementing MBT might be impeded by contextual, cultural, or experiential challenges. Additional factors for consideration might include the perspectives grounded in the literature on teacher beliefs and orientations (Luft & Roehrig, 2007).

MBT is an advanced pedagogical strategy involving a number of teacher moves and instructional strategies that overlap with other pedagogical frameworks. Exploring the impact of MBT on advancing other pedagogies may further support the importance of MBT proposed by this study.

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APPENDIX A  
KNOWLEDGE OF SCIENTIFIC MODELS QUESTIONNAIRE

1. Please state your full name.
2. How would you define the term “scientific model”? Can you provide some examples? (Modified from Crawford & Cullen, 2004)
3. If you were going to make a scientific model, what characteristics would the model need to have to be considered “high quality”? (Modified from Crawford & Cullen, 2004)
4. How and why do scientists use scientific models? Please provide specific examples if possible.
5. How do you use models in your teaching? If you don’t use models, why not? If you do use models, please provide a few specific examples of what models you use and how you use them.
6. Is teaching about models important in your area of science? Why or why not? (Crawford & Cullen, 2004)
7. In your opinion, what do your students understand by the word “model”? Why do you think that? (Justi & Gilbert, 2002)
8. In your classroom, do students produce their own models? If so, what do you do with them? If not, why? (Justi & Gilbert, 2002)
9. In your opinion, could/should models used in teaching be different than models used by scientists? Please explain your answer. (Justi & Gilbert, 2002)

## APPENDIX B

### KNOWLEDGE OF SCIENTIFIC MODELS SCORING RUBRIC

Table B.1

*Knowledge of Scientific Models Scoring Rubric*

	Uninformed	Developing	Proficient	Exemplary
<p>Dimension 1: Nature of Scientific Models and Modeling</p> <p>(Questions from KSM—2, 3, 4)</p>	<p>Models are defined as physical replicas or copies of something else.</p> <p>Differences between models and the target are not described.</p> <p>Qualitative characteristics of models are not described or are incorrectly described.</p> <p>The purpose of the model is not mentioned.</p>	<p>Models can represent abstract ideas or natural phenomena that are either too small, too large, or otherwise inaccessible.</p> <p>Differences between a model and its target are mentioned but not elaborated.</p> <p>Models are primarily used to describe something else, are static in nature, and accuracy is the primary characteristic.</p> <p>May mention explanatory purpose but no elaboration is provided.</p>	<p>Models are primarily explanatory tools used by scientists to communicate their understanding of something.</p> <p>The differences between a model and its target are discussed and connected to the purpose of the model.</p> <p>A model has a purpose that is considered in the development of the model. (May mention prediction but no elaboration)</p>	<p>Models are always related to a target and as such are purposefully constructed to be predictive, explanatory, and/or descriptive.</p> <p>They embody all of the characteristics of the Nature of Science (tentative, subjective, etc.) as they are the primary process and product of science.</p> <p>Multiple models may exist for the same phenomena and depend on the purpose for which the model is to be used.</p>

<p>Dimension 2: Scientific Models as connected to the Discipline of Science</p> <p>4, 5, 9</p>	<p>No connections to the Nature of Science (tentative, subjective, etc.) are apparent.</p>	<p>Scientists use models to describe what they know.</p> <p>Models are part of the scientific method (primarily in the description of findings).</p> <p>Some simple connections to the Nature of Science (tentative, subjective, etc.) are apparent.</p>	<p>Scientists use models in a variety of ways including describing or explaining their findings.</p> <p>Multiple connections to the Nature of Science (tentative, subjective, etc.) are apparent.</p>	<p>Scientists use models for describing, explaining, and predicting new phenomena.</p> <p>Scientists may use multiple models for the same phenomenon.</p> <p>They embody all of the characteristics of the Nature of Science (tentative, subjective, etc.) as they are the primary process and product of science.</p>
<p>Dimension 3: Scientific Models as connected to teaching science (Modeling Pedagogical Knowledge)</p> <p>6, 7, 8</p>	<p>No evidence of student knowledge of models.</p> <p>Models are not used in the classroom.</p>	<p>Awareness of student understanding of models is similar to their own (usually uninformed) understanding of models.</p> <p>Models are used to teach the content of the model, not the process of science.</p> <p>Students are never engaged in the generation of models but may</p>	<p>Teaching models are congruent but simplified versions of the scientific model.</p>	<p>Students engage in the process of scientific modeling in order to build their own content knowledge.</p>

		<p>be engaged in the use of a model as a learning tool.</p> <p>Models are useful but not cost effective in the classroom.</p> <p>Teaching models should be the same as scientific models.</p>		
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## APPENDIX C

### EQUIP DISCOURSE RUBRIC

Table C.1

*EQUIP Discourse Rubric (Marshall, Smart, & Horton, 2010)*





<b>V. Discourse Factors</b>					
<i>Construct Measured</i>	<i>Pre-Inquiry (Level 1)</i>	<i>Developing Inquiry (2)</i>	<i>Proficient Inquiry (3)</i>	<i>Exemplary Inquiry (4)</i>	
D1.	Questioning Level	Questioning rarely challenged students above the remembering level.	Questioning rarely challenged students above the <b>understanding level</b> .	Questioning challenged students up to <b>application or analysis levels</b> .	Questioning challenged students at various levels, <b>including at the analysis level or higher</b> ; level was varied to scaffold learning.
D2.	Complexity of Questions	Questions focused on one correct answer; typically short answer responses.	Questions focused <b>mostly on one correct answer</b> ; some open response opportunities.	Questions <b>challenged students to explain, reason, and/or justify</b> .	Questions required students to explain, reason, and/or justify. <b>Students were expected to critique others' responses</b> .
D3.	Questioning Ecology	Teacher lectured or engaged students in oral questioning that did not lead to discussion.	Teacher occasionally <b>attempted to engage students in discussions</b> or investigations but was not successful.	Teacher <b>successfully engaged students</b> in open-ended questions, discussions, and/or investigations.	Teacher <b>consistently and effectively engaged students</b> in open-ended questions, discussions, investigations, and/or reflections.
D4.	Communication Pattern	Communication was controlled and directed by teacher and followed a didactic pattern.	Communication was <b>typically controlled and directed by teacher</b> with occasional input from other students; mostly didactic pattern.	<b>Communication was often conversational</b> with some student questions guiding the discussion.	Communication was <b>consistently conversational with student questions often guiding the discussion</b> .
D5.	Classroom Interactions	Teacher accepted answers, correcting when necessary, but rarely followed-up with further probing.	Teacher or another student <b>occasionally followed-up student response</b> with further low-level probe.	Teacher or another student <b>often followed-up response</b> with engaging probe that required student to <b>justify reasoning or evidence</b> .	Teacher <b>consistently and effectively facilitated rich classroom dialogue</b> where evidence, assumptions, and reasoning were challenged by teacher or other students.

## APPENDIX D

### PERFORMANCE PROGRESSION FOR MODEL-BASED INQUIRY

Table D.1

*Performance Progression for Model-Based Inquiry (Thompson, Braaten, & Windschitl, 2009)*

<b>Where is my practice located? A Teacher's Performance Progression for Model-Based Inquiry</b>				
<i>Increasing order of sophistication of ambitious practices (practices on right-hand side may also include previous ideas)</i>				
<b>Ambitious Practices</b>  <b>1) Selecting big ideas, treating them as models</b>  	<b>Focus on topic or "things"</b> <ul style="list-style-type: none"> <li>Teacher selects concrete or abstract entities (things) to learn about in varying degrees of detail.</li> <li>Students asked to describe, name, label, identify, using correct vocabulary.</li> </ul>	<b>Focus on observable processes</b> <ul style="list-style-type: none"> <li>Teacher selects as focus "what is changing" in a system or how conditions affect a naturally occurring event.</li> </ul>	<b>Explanatory model focus (Aim for this!)</b> <ul style="list-style-type: none"> <li>Teacher focuses on <i>unobservable</i> processes, events, or entities, or the relationships among science concepts.</li> <li>Teacher links these to important <i>observable</i> natural phenomena in order to develop an explanatory model that students will make sense of over time.</li> </ul>	
<b>2) Attending to students' ideas</b>  	<b>Monitoring and re-teaching ideas</b> <ul style="list-style-type: none"> <li>Teacher starts by presenting information, then monitors language students use to see if students are developing "correct" conceptions (whether students "get it" or not).</li> <li>Teacher engages in 1-on-1 tutoring or uses IRE in whole class conversations to present more correct conceptions to students (perhaps using a different modality).</li> </ul>	<b>Eliciting students' initial &amp; unfolding understandings</b> <ul style="list-style-type: none"> <li>Teacher elicits students' initial and on-going hypotheses, questions, or conceptual frameworks about a scientific idea.</li> </ul>	<b>Referencing students' ideas &amp; adapts instruction (Aim for this!)</b> <ul style="list-style-type: none"> <li>Teacher elicits students' initial conceptions of a scientific idea by posing a rich open-ended task or puzzling event related to the big idea of the unit.</li> <li>Teacher listens for partial understandings as well as alternative conceptions (without presuming students need to precisely replicate the teacher's line of thinking).</li> <li>Teacher uses students' language and partial understandings as building blocks to shape the direction of classroom conversations. Teachers engineer productive classroom conversations or pursue students' lines of thinking by weaving students' lines of reasoning together with scientifically coherent ideas across multiple lessons.</li> </ul>	
<b>3) Choosing activity and framing intellectual work</b>  	<b>Primarily focusing on procedure</b> <ul style="list-style-type: none"> <li>Teacher asks students to describe procedures for activities or experimental set-ups.</li> <li>Science concepts are played down to allow time to talk about designing experiments.</li> <li>Talk with students is about how to do an activity or about error, validity, reliability, recording data.</li> </ul>	<b>Discovering or Confirming Science Ideas</b> <ul style="list-style-type: none"> <li>Teacher has students "discover" science concepts for themselves OR has students use an activity as a "proof of concept."</li> <li>Science is about acquiring accepted facts, principles, or laws. Students collect information to recognize or prove patterns.</li> </ul>	<b>Linking concepts within and across investigations</b> <ul style="list-style-type: none"> <li>Teacher first seeds students' thinking with new science concepts (not explanations) and asks students to use these ideas to make sense of an investigation.</li> <li>Science ideas are up for discussion. Students derive explanatory language from activity and use it to solve new problems. Public representations of students' ideas change in response to findings from each day.</li> </ul>	<b>Model-Based Inquiry focus (Aim for this!)</b> <ul style="list-style-type: none"> <li>Teacher highlights tentative or partial explanatory models as the basis for multiple investigations.</li> <li>Teacher asks students to use evolving model as a reference before, during and after each inquiry. Teacher builds in background knowledge of underlying (unobservable) science ideas and models before, during, and following an inquiry, but without doing the reasoning for the students.</li> <li>Science is about revising and testing models to synthesize ideas and explain problems.</li> </ul>
<b>4) Pressing for explanation</b>  	<b>No press for a scientific explanation</b> <ul style="list-style-type: none"> <li>Teacher does not ask students to provide any form of explanation; or teacher uses "explain" to mean "justify" as in justify the existence of an entity or accepted fact.</li> <li>There is no event or process that is subject to explanation.</li> </ul>	<b>"What happened" explanation</b> <ul style="list-style-type: none"> <li>Teacher asks students to describe relationships between variables, differences between experimental groups, trends over time, or qualitative observations. "Explain what you see in the data."</li> </ul>	<b>"How/ partial why" something happened explanation</b> <ul style="list-style-type: none"> <li>Teacher asks students to hypothesize about reasons for relationships among variables or observations, and how these predict the ways some natural system will behave.</li> </ul>	<b>Causal explanation (Aim for this!)</b> <ul style="list-style-type: none"> <li>Teacher has students use unobservable events, processes, and entities to construct a causal story of why something happened. (may mean first supporting students through "what" and "how explanations" with goal of working toward "why explanations")</li> <li>Teacher unpacks learning about the nature of scientific explanations with students, and about "what counts" as evidence.</li> </ul>



## APPENDIX E

### COMPARISONS OF NATURE OF SCIENCE INSTRUMENT SCORES

Table E.1

*Comparisons of Nature of Science Instrument Scores (Laurel)*

Laurel	VOSE	VNOS-C
Imaginative	4.6 - strongly agree (Q3)	“Interpretation of data can vary in some cases...data can be used to make inferences” (Q8) “...data can be interpreted differently and that may require some imagination” (Q10)
Tentativeness Teaching the Tentativeness	(Q4) – 3.7 – agree  (Q12) – 5 – strongly agree	“Theories change because new evidence is discovered...”(Q4) “If we don’t learn the present theories we will never be able to make advances from that point” (Q4)
Theory and Law Relationship	Q7. 1.75- Misunderstands the relationship Q13. Teach the relationship is very important 4.75	
The Scientific Method Teach TSM	(Q9) – 3.9 – agree (scientists follow TSM) (Q10) – 4.6 – strongly agree	“science is a process of discovering information using data from repeatable experiments...” (Q1)

Table E.2

*Comparisons of Nature of Science Instrument Scores (Carla)*

<b>Carla</b>	<b>VOSE</b>	<b>VNOS-C</b>
Imaginative	(Q3) – 4.4 - agree	“...[Scientists] use their imagination and creativity would be in planning and designing.” (Q10)
Tentativeness  Teach Tentativeness	(Q4) – 4.0 – agree  Q12. 4.0 - agree	“[Science]... is inquiry, an on going investigation, and continuously questioning process, and derives from observation and continuous study.” (Q1) “Science is changing rapidly because of technology and what we believe today may be obsolete tomorrow.” (Q4) “I think scientific theories do change. As scientist continue to observe, question, improve technology, and conduct experiments, they discover many of their theories are correct, but some are not.” (Q4)
Theory and Law Relationship	Q7. Misunderstands the relationship 2.0  Q13. Teaching about relationship is not important 2.3	“Theories are simply used to explain certain observed phenomena that has been proven to some degree and is a conjecture or educated guess. We have theories because it is a systemized way to try to get to another theory. Science is an on going study to ever changing phenomena. The theory of man evolving from tadpoles and the theory of humans evolving from monkeys are very debatable issues. Each theory has enough evidence to give weight, but neither has been proven. “ (Q4)
The Scientific Method  Teach TSM	(Q9) – 3.7 – agree with TSM  (Q10) – 3 – neither agree nor disagree	“Science is a systematic study explaining the creation of the universe to the existence of life as we know it today.” (Q1) “Religion seeks to teach us the truth and science works to uncover reality. Reality and truth are the same thing. Science is the study to uncover the reality while religion is the way to truth.” (Q1)

Table E.3.

*Comparisons of Nature of Science Instrument Scores(Andy)*

<b>Andy</b>	<b>VOSE</b>	<b>VNOS-C</b>
Imaginative	Q3 – 4.0 – agree	“Interpretations of experimentation are left to scientists' imagination as to how these results support or reject [their] positions/thoughts.” (Q8) “Imagination and creativity are most effective in the design of an investigation.” (Q10) “Imagination and creativity are essential to the scientist. Scientists must draw on their background knowledge, new evidence, and recognition of unique phenomenon and how these might be associated in nature. Scientists must use their imagination and creativity to logically and accurately make the connections.” (Q10)
Tentativeness Teach Tentativeness	Q4. – 4.0 - agree Q12. 4 - agree	“An example of the progression of a theory would be the atomic theory from Dalton’s solid particle atom to the current electron cloud model.” (Q4)
Theory and Law Relationship	Q7. 4.0 Informed view of the relationship Q13. Teaching the relationship 4.0	“Scientific theories are explanations of natural events. As our understanding of these events change then the theories are updated with new information” (Q4)
The Scientific Method Teach TSM	Q9. – 3.7 agree Q10. – 4.0 agree	“Science is the application of the scientific method to discover new knowledge” (Q1) “[Only] With appropriate background support and collegial concurrence can a creative data collection method be implemented.”