CHANGES IN PRESERVICE SCIENCE TEACHERS’ KNOWLEDGE OF INQUIRY
AND PRACTICE OF LESSON DESIGN

BY

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ABSTRACT

Changes in Preservice Science Teachers’ Knowledge of Inquiry and Practice of Lesson Design

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Recent reforms in science education require teachers to improve their notions of scientific inquiry and design effective inquiry-based lessons. This is a challenging task particularly for preservice teachers (PTs) who may not have experienced inquiry learning themselves, and who do not possess a large repertoire of teaching strategies or knowledge of student thinking in the domain. PTs’ ability to apply knowledge in the planning and designing of inquiry-based lessons requires careful scaffolding in a science teacher preservice program. My study addressed some of these challenges. Specifically, I examined the ways that PTs’ knowledge of model-based science inquiry and their ability to use this knowledge in designing lessons developed over time. My study involved the 2006 cohort of 15 PTs enrolled in four subject-specific methods courses in consecutive semesters as part of a two-year biological science certification program. I employed qualitative procedures (coding, constant comparative method to identify themes, and quantifying qualitative analyses of these themes) to analyze teaching philosophy papers, clinical interviews, lesson plans, and final reflection papers collected from the methods courses.
My research findings provided evidence to support positive changes in PTs’ knowledge of Model-Based Inquiry (MBI) and its implementation in lesson designs. PTs were able to design lessons with (a) objectives that incorporated “big ideas” in science, (b) performance-oriented goals, (c) driving questions to elicit students’ pre-conceptions, and (d) multiple forms of assessment to monitor student progress. Moreover, I found several shifts in PTs’ knowledge of MBI and its enactment in lessons: (a) from teacher-centered and activity-oriented to more student-centered lessons with modeling, and (b) from “scripted” to more sophisticated modeling practice. These findings pointed to growth in the PTs’ use of models and practice of modeling, and consideration of students’ prior knowledge and skills. On the other hand, PTs struggled to provide suitable evidence for their students to use as part of investigations and failed to incorporate argumentation as part of the science practices in their lessons. My dissertation study has the potential to contribute to teacher education research by uncovering the effects of subject-specific methods courses and fieldwork on the growth of teacher knowledge of model-based science inquiry and inquiry-based instruction, lesson-planning practices, and knowledge of students’ conceptions and skills.
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DEDICATION

I dedicate my dissertation to my entire family, especially to my parents, Zaida and Augusto Macalalag Sr., who have supported and encouraged me to pursue my dreams.

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Chapter 1: Introduction

Current reforms require teachers to improve their notions of scientific inquiry and design effective inquiry-based lessons (National Research Council [NRC], 2000, 2011). This is a challenging task particularly for preservice teachers (PTs) who may not have experienced inquiry learning themselves, and who do not possess a large repertoire of teaching strategies or knowledge of student thinking in the domain (Crawford, 2004; Hayes, 2002; Schwarz & Gwekwerere, 2007). The purpose of my dissertation is to develop an understanding of the ways in which PTs’ knowledge of inquiry and their ability to design inquiry-based lessons change over time. The PTs in this study were enrolled in a two-year certification program in biological science education at a large public university on the east coast of the U.S. I analyzed educational philosophy papers, semi-structured interviews, reflection papers, and teacher-developed lesson plans that were collected during four consecutive methods courses from 2007 to 2009. This study builds upon the research on PTs’ knowledge of scientific inquiry as related to teacher practices such as planning, designing, and revising inquiry-based lessons. My dissertation study has the potential to contribute to the teacher education research by uncovering the effects of subject-specific methods courses and fieldwork on the growth of teacher knowledge of MBI and inquiry-based instruction, lesson-planning practices, and knowledge of students’ conceptions and skills.

1.1 Statement of the Problem

In this section, I describe the challenges in science teacher education that motivated my research. These challenges pertain to improving the knowledge and lesson-
planning practices of PTs, specifically around model-based scientific inquiry in the context of teacher preparation programs.

1.1.1 Challenges in science teacher education.

Following science education reforms in the 1980s and 1990s (National Commission for Excellence in Education, 1983; National Academy of Sciences & National Academy of Engineering, 1982; American Association for the Advancement of Science [AAAS], 1993), the National Science Teachers’ Association (NSTA) published a set of national science education standards that included standards for the preparation and continuing education of teachers (NRC, 1996). The science teaching standards describe what teachers of science at all grade levels should know and be able to do. Specifically, teachers of science are asked to plan and implement inquiry-based science instruction to facilitate learning in a more student-centered learning environment. However, in the same decade, most higher education institutions failed to meet the NSTA’s standards, and different institutions espoused different conceptions of scope, sequence, and breadth in preparing science teachers (Coble & Koballa, 1996). Moreover, the Rising Above the Gathering Storm (RAGS) report, published in 2007 by the Committee on Prospering in the Global Economy of the 21st Century, showed alarming trends in the lack of competitiveness of students, teachers, and scholarly publications in science, technology, engineering, and mathematics (STEM) in the U.S. compared to other industrialized nations. One of the recommendations was to increase the funds to support teacher preservice and inservice programs and research to improve teachers’ content knowledge, skills, and experience in STEM disciplines (Committee on Prospering in the Global Economy of the 21st Century, 2007).
Concerns and recommendations in these policy documents point to improvements in the preparation, induction, and professional development of science teachers (Davis, Petish, & Smithey, 2006). Teachers play a major role in the classroom wherein they have the ability to create and mold the environment in which students can effectively learn. In the words of Shulman (1987), teachers in their classrooms can “transform understanding, performance skills or desired attitudes or values into pedagogical representations and actions” (p.7). Moreover, teachers’ disciplinary content knowledge influences the learning environment, student interactions, and student learning (Etkina, 2010; Gess-Newsome & Lederman, 1995; Sanders, Borko, & Lockard, 1993). Unfortunately, variation in the quality of preservice preparation, qualifications, and resources of teachers result in widely different learning opportunities for different groups of students (Duschl, Schweingruber, & Shouse, 2007). Teacher preparation programs around the country lack consensus on how to prepare science teachers effectively (Windschitl, 2005).

The American Educational Research Association (AERA) in 2005 compiled a report based on research studies pertaining to the teacher education in the U.S. (Cochran-Smith & Zeichner, 2005). The AERA panel’s objective was to synthesize existing research and to craft a new research agenda to address gaps and holes in teacher education. Findings on the effects of PTs’ coursework showed that teachers who participated in a more subject-specific course of study (e.g. Biology, Chemistry) and had preparation in education (e.g. a methods course in teaching biology) had a positive effect on student achievement. For instance, Druva and Anderson (1983) found a positive relationship between pupil achievement and the number of science content courses taken by their teachers — the more courses taken by their teacher, the better content knowledge
(based on test scores) and attitudes (based on surveys) of students toward science. Other relevant findings from the Cochran-Smith and Zeichner (2005) review suggested that (1) most PTs have only a superficial understanding of subjects they will teach even after taking coursework in sciences and in education, (2) it was challenging for PTs to apply what they learned in their methods courses to their field experiences or practicum, and (3) PTs often felt conflict among messages from different instructors, field-based teacher educators, and school settings. To address some of the challenges and recommendations that I mentioned above, a preservice education program with subject-specific methods courses was developed for science teachers. Specifically, the PTs in my study participated in four consecutive methods courses in biology that focused on improving their knowledge and practice of MBI instruction, which I describe in chapter 3. In the next section, I discuss the successes and challenges of preparing PTs to teach science.

1.1.2 The use of model-based science inquiry in preservice science teacher education.

Current reforms advocate for science teaching that emphasizes the development of scientific knowledge through engagement in core scientific practices such as modeling, developing explanations, and engaging in argumentation (Duschl, Schweingruber, & Shouse, 2007; NRC, 2011). These new perspectives on scientific practices “minimize the tendency to reduce science practice to a single set of procedures such as identifying and controlling variables…[as well as a] tendency to overemphasize experimental investigation at the expense of other practices such as modeling, critique, and communication” (NRC, 2011, p. 3). This entails teachers developing knowledge and
practices of science as well as a reform-oriented pedagogy of teaching science. Specifically, teachers must view science as a set of practices that incorporate the following principles: (a) that scientific knowledge is built over time through theory-building and argumentation within the scientific community; (b) that claims may change in light of new evidence; (c) that no single scientific method exists, but there are shared common practices of doing science; (d) that the primary goal of science is to form, test, and revise models; and (d) that human interpretation and discourse play a vital role in the development of scientific knowledge (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; NRC, 2011).

The pedagogical approach associated with teaching science as model building and testing is termed Model-Based Inquiry (MBI). MBI in the classroom entails (a) the use of students’ prior knowledge to pose problems and generate data, (b) the search for patterns in data, (c) the development of causal models to account for patterns, (d) the use of patterns in data and models to make predictions, (e) the design and conducting of experiments to test models, (f) the revision of models based on evidence, and (g) the conducting of argumentation in light of new evidence (Etkina et al., 2010; Etkina & Van Heuvelen, 2007; Stewart, Cartier & Passmore, 2005; Windschitl & Thompson, 2006). MBI is contrasted with more “cookbook” procedures or simple investigations that involve comparing and contrasting of variables that are common in classrooms today (Chinn & Malhotra, 2002). It is also different from the traditional scientific method approach in that questions are derived from a model that represents observable (e.g. balloon expanding) or unobservable (e.g. collision of molecules inside the balloon)
phenomena in the world, rather than being based on what teachers conceive as interesting or doable (Windschitl, 2009).

MBI instruction reflects the philosophical stance of the constructivist theory of learning wherein students construct their own understanding of the natural world through their inquiry activities and reflections on those experiences. Students evaluate and negotiate new information based on their prior knowledge, beliefs, experiences, and evidence. At the same time, teachers facilitate learning experiences of students by facilitating students’ investigations and explorations, using students’ prior knowledge to motivate new learning experiences, and by challenging them to go beyond their current level of understanding (Etheredge & Rudnitsky, 2003; Vygotsky, 1986). Proponents of MBI in the classroom argue that “modeling promotes students’ opportunities to craft their identities as inventors of models, not simply as appliers of models from a textbook. They come to believe in their capacity to make contributions that are novel, rather than merely to replicate contributions made earlier by others” (Lehrer & Schauble, 2006, p. 384).

Developing their own knowledge of scientific modeling and placing emphasis on students’ active role in constructing and testing scientific models are challenging tasks, particularly for PTs. This is largely because PTs may not have experienced MBI learning themselves and do not possess a large repertoire of teaching strategies or knowledge of student thinking in the domain. Moreover, knowledge of MBI alone is not sufficient to change teaching practices and PTs need experience in designing MBI instruction and implementing it with students (Withdschitl & Thompson, 2006).

Central to MBI teaching is crafting instruction that fosters students’ capacity to (a) generate and evaluate scientific evidence and models of natural phenomena, (b)
understand the nature and development of scientific knowledge, and (c) participate productively in these scientific practices and discourses (Duschl et al., 2007; Duschl & Duncan, 2009). Recent studies have shown that engaging in teaching practices that will engender such practices is challenging for PTs (Friedrichsen et al., 2009; Windschitl & Thompson, 2006). Moreover, helping PTs develop MBI teaching practices entails careful scaffolding in methods courses to improve PTs’ abilities to design lessons that consider several important aspects of instructional design. These include: (a) sequencing of ideas in ways that build upon students’ prior knowledge or skills, (b) knowing the difficulties students may have in understanding scientific modeling, and (c) pursuing multiple ways of assessing students’ knowledge of scientific modeling (Etkina, 2010; Macalalag & Duncan, 2010; Schwarz & Gwekwerere, 2007).

Preservice and beginning teachers face a number of challenges in learning how to teach MBI effectively. These challenges include developing their own knowledge of scientific models and modeling (Windschitl, 2004; Justi & Gilbert, 2002), developing MBI lessons (Schwarz & Gwekwerere, 2007), and focusing on students’ learning (Hayes, 2002). Research by Windschitl (2004) suggests that teachers hold different notions of inquiry, some closer to the accepted notion of authentic science than others. In his study, the majority of PTs and practicing teachers held “folk theories.” These PTs’ folk theories included the conceptions that (a) a hypothesis functions as a “guess” about an outcome but is not necessarily part of a larger explanatory system and (b) background knowledge is used to inform study but is not necessarily part of a hypothesis or a model that can be tested.
1.1.3 Teachers’ difficulties in designing lessons.

A reformed approach to teaching science and mathematics requires teachers and students to accept new roles. This means a shift in roles from teacher as transmitter of knowledge (e.g. lectures, didactics, cookbook labs) to teacher as coach and facilitator, and from students as passive receivers of knowledge to students as self-directed learners (Palincsar, Magnusson, Cutter, & Vincent, 2002). Attending and responding to students’ ideas in a lesson is challenging for teachers, but central to constructivist approaches such as MBI. Numerous studies have shown that teachers struggle to let go of the didactic approach to teaching and lack a repertoire of teaching strategies to both elicit and respond to students’ ideas. They often fail to engage students in the scientific processes of generating, testing, and revising hypotheses or models (Hayes, 2002; Jacobs, Martin, & Otieno, 2008; Singer, Hilton, & Schweingruber, 2005). Moreover, inservice elementary teachers were unsure of how students solved problems in mathematics, had difficulties in interpreting students’ written work, and were unaware of effective teaching strategies to help their students (Kazemi & Franke, 2004).

Successful MBI instruction also requires the conceptualization and design of new kinds of lessons. This is also challenging for most teachers and especially PTs (Schwarz & Gwekwerere, 2007; Windschitl & Thompson, 2006). Teaching is a complex process that involves the conceptualization of the teacher’s intent and then the execution of the plan in the context of the classroom given the particulars of student understandings. Lesson plans reflect teachers’ thinking and the multiple decisions that teachers make before actual instruction begins (Duschl & Wright, 1989). While lesson plans do not usually reflect the nuances and complexities of implementation, they can provide a
reasonable picture of teachers’ knowledge of inquiry and the ways in which this knowledge is applied to instructional design.

Several studies have shown that induction and inservice teachers often lack topic-specific knowledge about learners to plan effective lessons (e.g. Friedrichsen et al., 2009). In research studies that involved English language teachers in Australia, lesson planning focused on the teachers’ interests, selection of procedural-type activities, and not on students’ conceptions (Liyanage & Barlett, 2010). Findings from a series of lesson studies designed by PTs in mathematics suggested that initial discussions around lesson design focused on teachers imparting knowledge to their students through lectures. PTs tended to see real-world or hands-on examples for the lessons, but they viewed them as tools to demonstrate concepts rather than to foster reasoning (Fernandez, 2010). In cases in which PTs did show awareness of students’ knowledge, they failed to consider students’ conceptions while designing lessons (Gullberg, Kellner, Attorps, Thoren, & Tarneberg, 2008). Finally, as part of lesson design that incorporated MBI, several PTs failed to incorporate models and modeling in their instruction even after they improved their knowledge of this practice (Windschitl, Thompson, & Braaten, 2008). Overall, little is known about how PTs’ knowledge of inquiry informs their ability to design, revise, and implement inquiry teaching (Schwarz & Gwekwerere, 2007).

1.2 Purpose and Significance of Study

The purpose of this study was to examine the changes in PTs’ knowledge of MBI and its application to lesson design as a result of the four science methods courses. This study was conducted in the context of a teacher preparation program whose
overarching goal was to prepare PTs to implement instruction that focused on scientific inquiry with attention to scientific models and modeling (NRC, 2000, 2011; Windschitl, 2004), and the incorporation of MBI in lessons (Schwarz & Gwekwerere, 2007) with consideration of students’ prior conceptions and skills (Hayes, 2002). My research study has the potential to contribute to teacher education research by uncovering the effects of subject-specific methods courses and fieldwork on the development of teacher knowledge of MBI and inquiry-based instruction, lesson-planning practices, and knowledge of students’ conceptions and skills (Etkina, 2010; Jacobs et al., 2008; NRC, 2011; Windschitl, 2008). In the next chapter I present my review of literature based on PTs’ knowledge around scientific models and their challenges in developing MBI lessons.
Chapter 2: Review of Related Literature

This review is organized into four sections that relate to teachers’ knowledge of inquiry and lesson design specific to teaching through the model-based inquiry approach. In the first section, I describe MBI, including similarities and differences between MBI and other forms of inquiry. I also present the successes and challenges of improving inservice and preservice teachers’ knowledge of MBI. The second section reviews factors that influence inservice and preservice teachers’ decisions in designing lessons. I also include in this section the successes and challenges of helping PTs develop student-centered lessons as well as incorporate modeling into their lesson design. The third section describes how the PTs’ pedagogical content knowledge guided their design of lessons.

2.1 Inservice and Preservice Teachers’ Knowledge of Inquiry, Models, and Modeling in Science Teaching

Teaching through inquiry has a long history in science education. From the early 1960s until today, researchers and educators developed curricula (e.g. Elementary Science Study [ESS] and Biological Science Curriculum Study [BSCS]), standards (e.g., National Science Education Standards and AAAS’ Literacy Maps), and professional development programs to help teachers to incorporate inquiry in the classroom (Duschl et al., 2007). MBI as a focus of science education is more recent approach to inquiry. It has stemmed from research in the philosophy of science that has argued for the central role that models play in scientific inquiry, both in terms of artifacts of scientific thought and as fodder for new scientific explorations (Kuhn & Pearsall, 2000).
“A scientific model is an abstraction and simplification of a system that make its central features explicit and visible, allowing someone—the inquirer (a scientist, a teacher, or a learner) – to illustrate, generate explanations, or make predictions about natural phenomena” (Harrison and Treagust, 2000, p.2). A model is a set of conceptual understandings that (a) can be used to explain natural phenomena, (b) is continuously assessed and revised in light of new data and evidence, and (c) can be used to make predictions about natural phenomena and thus become a useful guide for future research studies (Cartier, Rudolph, & Stewart, 2001). The inquirer can create and use models in the form of analogies, conceptual drawings, mathematics, graphs, and physical simulations to describe and convey understanding about our natural world (Carey & Smith, 1993; Gilbert & Boulter, 1998; Lehrer & Schauble, 2006; Crawford, 2004). In addition, Carey and Smith (1993) described varying degrees of complexity in how scientists use these models. At the most basic level, models may be thought of as either toys or as simple copies of reality. As an understanding of modeling increases, the modeler’s ideas begin to play a role in the modeling process (through highlighting, simplifying, and creating different versions), although tests of the model are thought of as tests of the workability of the model itself, not of the underlying ideas. Finally, in the most mature understanding, the modeler takes an active role in constructing the model, and model can be manipulated and subjected to tests in the service of informing ideas.

Models are part of larger and more comprehensive systems of explanations or theories that guide questions, investigations, and interpretations of findings. A theory is a well-established principle that has been developed to explain some aspect of the natural world. Within a theory, there are different models that explain or describe its smaller
pieces, while hypotheses are made to test a model. Hypotheses are empirical conjectures (if this is true, then this should happen) that help test smaller piece of a model. For instance, atomic theory describes that matter is composed of discrete units called atoms. We know this, and we are still learning more, about the nature and behavior of atoms through various inquiry endeavors conducted by scientists over time. The Bohr model of an atom described electrons moving in circular orbits around the nucleus, while Schrodinger’s model suggested that electrons behave in a wave-like manner and that their exact location within an orbit cannot be precisely calculated. Both Bohr and Schrodinger proposed hypotheses and tested their models. For example, Ernest Rutherford conducted the gold foil experiment (in which he bombarded the foil with alpha particles) to test his hypothesis on the presence of a nucleus in the middle of an atom. The results of testing and revision of the atomic models contributed to our current understanding of atomic theory (Zumdahl & Zumdahl, 2003).

Consider another example of a geologist trying to explain the demise of trees along the coast of Oregon and Washington. Based on his prior knowledge and review of recent research, the geologist first created initial models and corresponding hypotheses to explain and test possible causes of tree deaths: (a) volcanic activity, (b) insect infestation, (c) presence of salt water in the soil given the location’s proximity to the Pacific Ocean, or (d) an earthquake. He then investigated the volcanic activity model by looking at the soil samples and outer tree rings. He found no evidence of volcanic deposits in his soil samples or burning, which ruled out the volcanic model. His experiments on outer tree rings also showed no evidence of insect infestation. He then proceeded to test the remaining models. In the end, through collaboration and further experimentation, he
found that a tsunami, accompanied by an earthquake, killed the trees not only along the coast of Oregon and Washington, but also in several countries in the Pacific (NRC, 2000). This example illustrates the role that models play in guiding research, and in turn, how research provides evidence to rule out or revise the models. Engaging in the development, testing, and revision of models is a core aspect of scientific work and thus should be a core aspect of science learning in the classroom (Duschl et al., 2007; Michaels, Shouse, & Schweingruber, 2008; NRC, 2011).

The teaching and learning of science through MBI involves understanding scientific knowledge as an ever-evolving set of conceptual models of natural phenomena and the scientific practices used to generate, test, and revise those conceptual models (Michaels et al., 2008). In model-based teaching, teachers develop lessons that engage students in (a) using prior knowledge to identify questions, (b) searching for patterns in data, (c) developing explanatory models to account for the observed patterns, (d) using models to make predictions that can be tested, and (e) revising the initial models in light of evidence from observations and tests through argumentation about the merit of models and evidence in the context of a community of learners (Stewart, Cartier & Passmore, 2005). MBI teaching reflects the current science education reforms’ shift in focus from teaching methods that emphasize the context of justification (e.g. theory testing) toward methods that emphasize context of discovery (e.g. theory building) (Duschl, 1990).

Moreover, one of the essential features of scientific practice is “a commitment to data and evidence as the foundation for developing claims… scientists need to be able to examine, review, and evaluate their own knowledge and ideas and critique those of others” (NRC, 2011, p. 2).
A comparison of MBI instruction with other approaches to science inquiry-based teaching presents several key similarities and differences. In contrast to MBI, previous views or approaches to inquiry tend to minimize the scientific practice to a single set of procedures (e.g. controlling variables, classifying entities) and have a tendency to overemphasize experimental investigation at the expense of modeling and argumentation. In addition, investigations or activities are often taught in isolation from the science content (NRC, 2011). Conceptual change instruction focuses on the changes in conceptual understandings of individual learners as a result of instruction that challenges students’ alternative conceptions. The instructional activities in the lesson are based on the learner’s prior knowledge and its development. The 5E model, another inquiry approach, argues that learners should: engage with a scientific problem or question, explore what they know or do not know about the problem or question, explain what they learned after engaging in an experiment and/or activity, elaborate on their understanding based on empirical evidence, and evaluate their learning through the application of knowledge to a different context. These approaches, along with MBI, reflect a similar philosophical stance towards student-centered learning in that they all emphasize the active construction of knowledge by students and all begin with students’ prior ideas. The instructional activities thus guide the development of students’ prior knowledge towards more canonical understandings. A key difference between these approaches and MBI is with regard to the value of engaging in knowledge-building activities that are common in science, such as modeling and argumentation. The conceptual change and 5E approaches do not focus on these scientific practices as important in and of themselves.
On the other hand, the Investigative Science Learning Environment (ISLE) approach, developed by Etkina and Van Heuvelen (2007), is very similar to MBI. In ISLE, students start each lesson by observing and looking for patterns in physical phenomena (e.g. a wet patch drying, light shadows). Then students develop explanations based on these patterns and use these explanations to predict outcomes of an experiment. Students use evidence from experiments to verify or refute the predictions based on explanations, finally revising explanations, if necessary, based on new evidence. Even though the ISLE framework does not use the term “models,” it shares similar features with MBI, such as engaging students in developing, testing, and revising explanations. Moreover, both frameworks consider the development of students’ conceptions and their active participation in the scientific process. However compared to ISLE, teachers who use MBI instruction do not always start the lesson with an observational experiment. Teachers can elicit students’ pre-conceptions or naïve models through questions or evidence (e.g. graphs, pictures) that are presented to them. Moreover, teachers of MBI can also start lessons by presenting models to students.

2.1.1 Successes and challenges of teaching through model-based inquiry.

Implementing model-based science inquiry is challenging even for inservice, or practicing, teachers. Justi and Gilbert (2002) studied 39 Brazilian elementary and secondary inservice teachers to assess their knowledge and attitudes regarding the use of models and modeling in learning science. Based on teacher interviews, they found that most teachers recognized the need to use models in order to make scientific concepts generally more understandable to their students. The special teaching models
(oversimplified and static models used for teaching or conveying information) were created by removing parts of a scientific model that were not relevant to their teaching or not congruent with the teaching purpose being addressed. This suggested that teachers did not seem to realize the difference between scientific models and models that they used in their instruction. Moreover, the majority of the teachers (90%) were only concerned with the use of scientific models in conveying scientific concepts, and not models created by their own students. Over half (59%) of the teachers positively valued engaging their students with modeling activities. However, only 21% of them expressed that despite the fact that they discussed their students’ models in class, student models were ultimately ignored in favor of existing scientific models. Finally, “when questioned about how they deal with the outcomes of students modeling activities, 72% of teachers said they would engage their students in the scientific process, 46% would use students’ models as a bridge to a scientific model, and 15% of them would not know what to do” (Justi & Gilbert, 2002, p.1286). This shows that the teachers struggled to understand the use and function of models in their science instructions.

Similar to inservice teachers, elementary PTs struggled to implement MBI instruction. Hayes (2002) used the National Science Education Standards’ essential features of inquiry-based instruction (NRC, 2000) to study understanding of this instructional approach in his research with 22 PTs enrolled in one semester of an elementary science methods course. The essential features he focused on included (a) guiding students to develop their own questions, (b) providing meaningful concrete experiences from which such questions could be generated, (c) facilitating open-ended student investigations, and (d) fostering a community of learning that works
cooperatively in its investigations. Hayes found that the PTs in his study struggled in their new roles as teachers of inquiry. Specifically, he uncovered three major difficulties: “letting go,” “going with” students’ interests, and asking the “right” questions. It was challenging for PTs to let go of the didactic or lecture approach to teaching and move towards a more student-centered instruction. It was also evident that most PTs were not sure how to use students’ interests to drive experiments and activities in the lessons due to the wide range of decisions to make and multiple directions to pursue (e.g. preparing the right experiments and materials for students). Moreover, the PTs were concerned about who should generate the inquiry questions and how to answer them. They believed that teachers had to provide answers to questions, otherwise students would not be learning.

Windschitl (2004) found that PTs held different notions of inquiry that did not reflect authentic science. In his multi-case study with 14 PTs enrolled in a secondary science methods course, PTs engaged in inquiry projects of their own choice and shared their own frameworks about what it means to do science. Windschitl’s analysis of journals, interviews, inquiry projects, and supervisor observations revealed that PTs struggled with the process of scientific inquiry. Specifically, the most problematic shortcoming in the versions of inquiry that PTs constructed was the absence of a guiding theory or scientific model. The development of hypotheses was characterized by PTs as their initial brainstorming of ideas or solutions to the questions, followed by experiments that they deemed interesting and doable. For instance, one PT proposed an inquiry project to determine which of the commercial fertilizers was better for plants and hypothesized that Green-Gro would work best since this chemical fertilizer was popular in the market.
This PT’s hypothesis functioned as a guess about an outcome, but was not part of a larger explanatory framework.

In a follow-up study, Windschitl and Thompson (2006) showed that PTs could improve how they think of models and yet still struggle to incorporate them in designing their investigations. Aside from the inquiry project, the instructional activities in their methods course focused on improving the PTs' thinking about the nature and function of models, helping them generate theoretical models to ground empirical investigations, and using elements of PTs' previous experiences with research to improve their understanding of models. Findings from their study indicated that (1) there was a strong positive relationship between PTs’ initial level of understanding of models and their belief that models could be used to teach the Nature of Science; (2) PTs developed more sophisticated understandings of scientific models—specifically, they generated models that were causal or descriptive, as well as hypothesis-driven; and (3) there was evidence that a good number of participants planned to incorporate models in their own teaching. On the other hand, participants failed to use theoretical models to ground empirical investigations in their inquiry projects. This was the result of limited use of modeling in the PTs schooling and widely-held simplistic views of the scientific method. In addition, Windschitl et al. (2008) saw that, initially, it was challenging for their PTs to use evidence from their experiments to develop arguments in their inquiry activity. The majority of PTs mentioned discussing or stating what they learned from their experiments instead of using evidence to engage in argumentation. However, after participating in several inquiry lessons, readings, and discussions as part of a methods course, PTs were able to imbed argumentation based on evidence and models in their MBI projects.
Moreover, there was a positive indication that PTs implemented modeling during their student teaching or practicum. Specifically, more than half of the PTs (8 of the 15) embedded modeling into their own instruction.

One study examined ways to improve PTs’ knowledge and practice of MBI by using computer software as a tool for developing conceptual models. Crawford (2004) used software called Model-IT to facilitate preservice science teachers’ understandings of modeling in science. In Model-IT, PTs used their own scientific knowledge to identify variables, along with quantitative or qualitative descriptions of the objects, to create relationships that described how variables affect one another. Furthermore, key features of the Model-IT process included PTs testing and revising their own models based on results of the test, new data, or interpretations of data. Findings from the study suggested that after one semester of engaging in modeling experiences PTs became more articulate in their language of modeling, and the computer modeling fostered their ability to think critically about mechanisms involved in modeling, designing open-ended investigations, and building and testing their own dynamic computer models. However, similar to the findings of Justi and Gilbert (2002), PTs viewed models as representations used by someone who understands to explain to someone who does not, which is different from how scientists or researchers use models. Finally, there was little indication in statements of their beliefs and intentions about their plans to use models and modeling in their own teaching.

In summary, fostering PTs’ understandings of model-based scientific inquiry is a challenging task, particularly for teachers who may not have experienced inquiry learning themselves, and who have a limited repertoire of teaching strategies. Teachers struggled
to let go of their didactic or lecture based instruction, to ask the right questions, and to focus on students’ interest and thinking. In addition, teachers thought of models as pedagogical aids but generally did not recognize the crucial role of models in guiding the generation of new knowledge. Consequently, they showed little attention to using models in these ways with their students. However, several studies showed that teachers were also capable of becoming more proficient in the language, use, and processes of modeling, and could develop complex understanding models as they gained more experience in inquiry learning and teaching. In the next section, I discuss the factors that influence lesson design of inservice and preservice teachers and the challenges of incorporating modeling into their lessons.

2.2 Teachers’ Planning and Designing of Lessons

Lesson planning is a ubiquitous practice for teachers and lesson plans are important artifacts of teaching. School administrators collect them, teachers share them with each other, and methods courses teach PTs how to craft them. The processes of lesson design and the creation of lesson plans are windows into teaching philosophy and strategies. Lesson planning refers to teachers’ conceptualization and formulation of courses of action in a lesson, which in turn have a profound influence on teachers’ classroom behavior and students’ learning (Shavelson, 1987). In planning and preparation, teachers demonstrate their knowledge of content and pedagogy in terms of student knowledge, selection of instructional goals, knowledge of resources, design of coherent instruction, and assessment of student learning (Danielson, 1996).
2.2.1 Inservice teachers’ lesson planning.

Several studies have explored aspects of experienced teachers’ lesson planning processes. Peterson, Marx, and Clark (1978) investigated the relationship between teacher planning, teacher behavior, and student achievement. Their study focused on 12 experienced teachers who taught social studies lessons to three groups of high school students. Findings from the analysis of planning statements of the teachers indicated that the largest portion of planning focused on the content to be taught and on selecting activities. A comparably small number of planning statements concerned the materials and the learner, and a very small number of planning statements mentioned lesson objectives.

Several factors affect teacher decisions while planning lessons. Brown (1998) conducted a case study of 12 middle-school inservice teachers’ yearly, unit, weekly, and daily planning. Analyses of written plans, think-alouds, and questionnaires indicated that the common factors that affected teachers’ planning included student ability (very often), district curriculum guides, orderly transition between activities, student attention, standardized tests, and undergraduate training (rarely). In a similar study, Duschl and Wright (1989) investigated inservice teachers’ decision-making models for planning and teaching of science. In their study of 13 high school teachers, they found that selection, planning, and designing of instructional tasks were dominated by considerations about student development, objectives set by the curriculum, and accountability pressures. However, teachers paid little attention to the scientific theories involved in their lessons. These studies pertain to inservice teachers and highlight the complexity of the lesson
design task and the different factors that influence teacher decision-making while planning lessons.

Teachers’ decisions while designing and implementing lessons are influenced by their own personal philosophies of teaching and not so much by a curriculum. Wieringa, Janssen, and Van Driel (2011) examined the extent to which the teachers’ personal “rules-of-thumb” relate to implementation of the Dutch biology curriculum, lesson planning, and design decisions in their classrooms. Interviews and classroom observations were collected from six biology teachers in the Netherlands. The new context-based biology curriculum aimed to increase relevance, student understanding, conceptual coherence, and student motivation. Its instructional design principles included (a) introducing the lesson using a context or situation from students’ life-world, society, or the scientific profession; (b) a question or a problem posed by a teacher or students based on the context; (c) student activities that would answer the question or problem as well as lead to an understanding of one or more biological concepts; and (d) students reflecting and summarizing the concepts learned from the lesson. Their research findings suggested that the teachers’ personal rules-of-thumb, which differed among different teachers, guided their decisions while designing lessons. This was more powerful in determining the lesson design than any formal prescribed curriculum or instructional design principles. Moreover, teachers in the study did not feel that using context-based instructional design principles would help their students learn the concepts in the lessons.

Workshops aimed towards helping teachers design lessons and problems as well as analyze students’ work helped teachers attend to students’ thinking in the field of mathematics. Kazemi and Franke (2004) engaged ten elementary teachers in regular
monthly workshops to design lessons and problems, discuss instructional strategies, analyze their students’ work, and reflect on students’ mathematical strategies or thinking while solving a problem. Findings suggested that initially, teachers were uncertain and unaware of the different ways their students solved math problems. They were unsure as to how students completed math problems (e.g. addition, subtraction), as well as the reasoning behind student solutions, and encountered difficulties in interpreting students’ written work. However, as the workshops progressed, teachers began to attend to their students’ thinking in ways that included eliciting student ideas, and to their surprise they started to notice the sophisticated strategies (estimating, rounding numbers, and organizing numbers into rows of tens) that students used in adding numbers. Understanding student ideas helped them design better lessons and problems with various teaching strategies (e.g. direct modeling, counting, deriving facts) aimed at solving a particular problem (e.g. measurement division, multiplication).

In addition, workshops can also provide teachers with opportunities to increase their knowledge of mathematics, attend to student ideas, and develop strategies to help their own students. After a 2-week workshop on lesson design and research study conducted by Lewis, Perry, and Hurd (2009), teachers increased their knowledge of solving math problems and were able to anticipate alternative solutions that students might pose. These included distinguishing patterns in series of triangles in a geometry problem and determining what would change the pattern (e.g. arrangement of triangles). Moreover, teachers improved their pedagogical knowledge as part of lesson design and learned to better incorporate student thinking in designing lessons. This included knowing that completing a worksheet with math problems does not always equate to an
understanding of patterns as well as recognizing the role of data organization in helping students learn.

2.2.2 Preservice teachers’ lesson planning.

The state of affairs regarding PTs’ lesson planning is similarly complex. Several research efforts to study the development of PTs’ ability to design lessons, specifically inquiry-based lessons, have met with mixed success (Friedrichsen et al., 2009; Schwarz & Gwekwerere, 2007; Windschitl et al., 2008). Friedrichsen et al. (2009) analyzed the lessons developed by four teachers in a certification program—two with two-years of teaching experience and two without any teaching experience—to investigate differences between the two groups. Their analysis of the lessons revealed that both groups relied primarily on their subject matter knowledge and on general pedagogical knowledge to plan the lessons. Both groups of teachers lacked topic-specific knowledge about learners, instruction, curriculum, and assessment. Friedrichsen and colleagues found that a typical lesson for both groups began with the teacher asking questions, followed by a lecture, and then guided practice designed so students could memorize and practice the lecture material; these lessons were mostly teacher-centered. Their research suggested that PTs, in either group did not tend to take students’ prior knowledge or the district’s curriculum into account when designing lessons, nor did they have the necessary pedagogical content knowledge to address specific ideas that students may have had about the content.

Designing student-centered lessons is difficult not only for PTs in science and mathematics but also for PTs in other disciplines. However, it is possible for preservice teacher education to influence PTs’ practices of lesson planning and design. Liyanage
and Bartlett (2010) studied nine prospective English language teachers in Australia as they engaged in lesson planning, implementation, and evaluation/reflection. Their findings suggested that PTs increased their knowledge of how to construct a student-centered lesson plan and showed a core shift away from planning based on management needs of the teacher to planning that would fit the learning needs of students. Specifically, PTs moved away from procedural-type lessons to focus more on students’ conceptions. In addition, PTs became more explicit in linking the lesson objectives to the instructional methods of the lesson. This included becoming cognizant about questions of what to teach through an activity, what students might learn from it, and how these activities are going to help foster the lesson’s overall objective.

Examining lesson planning and design can elucidate PTs’ initial conceptions about students’ understanding of both science and mathematics. Gullberg, Kellner, Attorps, Thoren, and Tarneberg (2008) helped 32 PTs develop science and mathematics lessons that considered students’ conceptions. Analyses of lessons showed that two-thirds of the PTs said that it was important for them to understand their students’ prior conceptions. Most of those who were aware of the importance of knowing students’ prior knowledge tried to increase their knowledge of students’ prior conceptions by embedding questions in the lessons to elicit student ideas. About a third of PTs suggested that students’ ideas depend on individual knowledge and experiences. A few PTs expressed vague or limited conceptions about students’ knowledge and potential difficulties in the lesson. However, even in instances in which PTs showed awareness of students’ knowledge, about one-third of them did not take into account students’ conceptions while planning their lessons.
In contrast, Fernandez (2010) showed that it was possible for PTs to conceptualize and design student-centered lessons that accounted for students’ conceptions. Fernandez worked with 18 PTs enrolled in a mathematics methods course involving a series of microteaching assignments. As part of their microteaching, PTs participated in (a) a collaborative lesson planning, (b) lesson observation by other PTs and course instructors, (c) microteaching of lessons, and (d) ongoing reflection and revision of lessons. Findings suggested that PTs’ initial discussions of lesson designs focused on teachers imparting knowledge through didactic methods to their students. PTs tended to seek real world or hands-on examples for lessons, but they viewed them only as tools for them to show or demonstrate concepts and relationships, and not as ways for students to create knowledge themselves. As the PTs progressed in the course and lesson study, lessons became more centered on eliciting students’ reasoning, exploration, and construction of mathematical ideas. PTs moved away from simply explaining the formulas and relationships to having students construct knowledge themselves. Moreover, prospective teachers began to consider students’ conceptions or abilities that might impede their exploration of concepts. Finally, decisions about selecting hands-on examples shifted to providing students with sufficient and suitable examples for them to examine patterns and create mathematical relationships or concepts rather than teachers explaining and making the connections for their students.

Methods courses have contributed to the improvements of PTs’ practices of lesson design that focuses on students’ ideas. In particular, PTs improved their knowledge of models in physics and were able to create student-centered lessons by the end of four consecutive methods courses as part of a teacher certification program in
physical sciences (Etkina, 2010). In particular, PTs improved their ability to design lessons at the end of Methods II (in a four methods course sequence). Lessons included identification of appropriate learning goals, standards, students’ prerequisite knowledge, science concepts, and assessments. Moreover, classroom observations conducted after PTs graduated from the program showed that as beginning teachers, these PTs engaged their students in active exploration of phenomena (solving problems and conducting experiments) as part of science instruction.

While there is research about facilitating PTs understanding of student-centered teaching, there are few studies that have explored the effects of supporting PTs in developing understandings of and using MBI teaching, and these demonstrate PTs incomplete mastery of the approach. For example, Schwarz and Gwekwerere (2007) studied the effects of providing a highly-scaffolded MBI framework called EIMA (Engage-Investigate-Model-Apply) with 24 PTs enrolled in a semester of elementary science methods course. In their study, the PTs were successful in designing lessons that engage students in science inquiry using models. The EIMA instructional framework enabled the majority of PTs to move their teaching orientations away from didactic approaches and toward reform-based approaches such as conceptual change, guided inquiry, and modeling. However, PTs still struggled with incorporating models into their lessons. One possible reason was that the PTs’ understanding of the nature of scientific models fell short of how actual scientists view models. Specifically, PTs’ referred to “creating models” in their lesson plans as the creation of examples representing objects or phenomena. While this may be useful for instruction and not totally incorrect, this may not lead them to predict or explain phenomena in the way that scientists use models.
Schwarz and Gwekwerere (2007) suspect that this shortcoming may be attributed to the different uses of the word “models” in the sciences, education, and the English language. In particular, the word “model” was used in multiple contexts and forms (e.g. instructional models, physical models, mental models, conceptual models, etc.) during their methods course.

In summary, research studies have shown the different challenges that inservice and preservice teachers faced while engaging in lesson planning and design. Specifically, inservice teachers paid little attention to the scientific theories involved in science lessons (Duschl & Wright, 1989) and were initially uncertain and unaware of the different ways of thinking about concepts among their students (Kazemi & Franke, 2004). However, through professional development, inservice teachers can begin to attend to their students’ thinking; specifically, they can learn to recognize the sophisticated strategies elementary students used while adding numbers (Kazemi & Franke, 2004).

In contrast, PTs have tended to design lessons that were teacher-centered, which did not consider students’ prior knowledge and the curriculum (Friedrichsen et al., 2009). In a study that helped PTs increase their knowledge of students, about one-third of the 32 PTs did not consider students’ conceptions while designing lessons. On the other hand, several studies have shown that it was indeed possible for PTs to conceptualize and design student-centered lessons (Etkina, 2010; Fernandez, 2010; Lewis, Perry, & Hurd, 2009). The workshops and methods courses in these studies were designed to support PTs in eliciting students’ conceptions or identifying variations in ability that might impede their explorations of concepts while engaging in lessons. Finally, Schwarz and Gwekwerere (2007) found that it was challenging for PTs to incorporate MBI into their
lessons. These concerns (students, instructional strategies, etc.) may have roots in PTs’ pedagogical content knowledge in lesson design, which I discuss in the next section.

2.3 Pedagogical Content Knowledge in Lesson Design

Effective science teaching involves “special understandings and abilities that integrate [teachers’] knowledge of science content, curriculum, learning, teaching, and students… such knowledge allows teachers to tailor learning situations to the needs of individuals and groups” (NRC, 1996, p.62). This knowledge of teaching is called pedagogical content knowledge (PCK), which is defined by Shulman (1987) as the “special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding” (p.8). I adapted the PCK framework from Magnusson, Krajcik, and Borko (1999) to examine PTs’ PCK for MBI as manifested in their lesson and unit designs. This adapted framework included:

(a) MBI as the orientation to teaching,
(b) knowledge of MBI curricula,
(c) students’ knowledge and difficulties pertaining to scientific modeling,
(d) strategies and activities used to scaffold student understanding of scientific modeling, and
(e) knowledge of assessment strategies for assessing students’ knowledge of modeling.

I describe each of these elements below.

First, MBI as an orientation to teaching science refers to teachers’ knowledge and beliefs about the goals for teaching science at a particular grade level. Specifically, this
refers to an understanding of science that includes models and engaging students in scientific modeling practice that leads to learning. PTs’ orientation toward MBI teaching is essential in selecting appropriate motivational strategies and driving questions to elicit students’ prior knowledge, as well as in selecting appropriate goals and activities (e.g. modeling and experiments) to guide students’ science content-learning experiences (Gess-Newsome & Lederman, 1999).

The second aspect of PCK of MBI, *knowledge of curricula*, refers to PTs’ selecting or identifying suitable instructional goals and appropriate materials for students, as well as their articulation and consideration of different topics addressed in a unit of study or lesson (Magnusson et al., 1999). The goals are reflective of the “big ideas” and practices in science as manifested in the national and local benchmarks and standards (e.g. AAAS, 1993, state standards), are informed by students’ prior learning experiences, and are performance-based and measurable (Danielson, 1996; AAAS, 1993). Furthermore, part of the knowledge of curricula includes the teachers’ ability to identify, adapt, or create appropriate resources such as evidence to be used in a science lesson.

The third component of PCK involves the PTs’ understandings of students’ conceptions and difficulties pertaining to MBI. Science teaching involves a student-centered learning environment wherein students of science generate, evaluate, and test scientific models (NRC, 2011). PTs’ lesson design must reflect a student-centered learning environment that incorporates students’ generating scientific models, designing and conducting experiments to test their models, revising the models based on evidence, and conducting argumentation in light of new evidence, which are the cornerstones of MBI (Stewart, Cartier, & Passmore, 2005; Windschitl & Thompson, 2006). In particular,
the lesson design or plan uses the process of scientific modeling to actively solicit students’ preconceptions and carefully articulates how these preconceptions or naïve understandings will be built upon in the lesson (Schwarz, 2009). Moreover, part of the teachers’ PCK in this area is the ability to anticipate potential sources of students’ difficulties in learning a particular science concept or practice. In some cases, learning can be difficult because concepts are very abstract to students and/or they lack experience with the topic. In other cases, students lack experience in how to engage in scientific practices such as those involved in MBI. Finally, knowledge of learners’ history allows PTs to design lessons that will build upon students’ prior learning and experiences.

A fourth aspect of PCK of MBI is knowledge of instructional strategies, which relates to teachers’ ability to incorporate scientific modeling into the lesson and to move students’ thinking forward using this pedagogical approach. It points to PTs’ lesson designs that engage students in developing questions, designing experiments, building and revising models, and facilitating classroom discourse (Schwarz & Gwekwerere, 2007). This aspect of PCK concerns instructional strategies in selecting real-life examples as part of the motivation to learn or activities in the lesson that can be used to make students learning successful.

Finally, there is the aspect of PCK that relates to knowledge of assessments for students engaging in MBI. Proposed assessments must be relevant to the objectives and provide sufficient detail about the content and practices being assessed. Moreover, the lesson plan must include appropriate and varied ways of assessing students’ knowledge throughout the lesson (Duschl, 2003). An instructor can plan and adjust his or her lessons to help students learn the objectives by capturing students’ conceptions and difficulties.
Assessments can take the form of students’ revising their naïve models and explaining them based on evidence, a unit test, and/or a culminating project.

2.4 Summary

Teaching science through inquiry and developing inquiry lessons specifically around models and modeling is challenging for PTs. These challenges include (a) difficulty in letting go of the didactic approach to teaching and moving toward more student-centered instruction (Hayes, 2002) and (b) not referring to scientific theories or models in planning and performing their investigations (Windschitl, 2004). In studies that looked at the ways to improve PTs’ knowledge and language of models and modeling, Crawford (2004) was successful in developing PTs’ ability to critically think about mechanisms involved in modeling after one semester of engaging in modeling experiences, designing open-ended investigations, and building and testing their own dynamic computer models. However, PTs viewed models differently from the ways that scientists or researchers use models, there was little indication of using modeling in PTs’ own teaching, and these PTs failed to use models to design their own investigations (Crawford, 2004; Justi & Gilbert, 2002; Windschitl & Thompson, 2006).

In terms of the teachers’ ability to design inquiry-based lessons, very small numbers of inservice teachers’ lesson planning statements were concerned about the learners (Brown 1993, 1998; Peterson et al., 1978). In research where inservice teachers considered student development, they paid little attention to the scientific theories involved in the lesson (Duschl & Wright, 1989). As for PT’s lesson planning,
Friedrichsen et al. (2009) found that a typical lesson was mostly teacher-centered. On the other hand, through workshops or methods courses, PTs were shown to be capable of increasing their knowledge of science or mathematics, attending to student ideas, and learning teaching strategies to help their own students (Etkina, 2010; Lewis, Perry, & Hurd, 2009). Finally, Schwarz and Gwekwerere (2007) showed that by using highly-scaffolded frameworks for instructional design, PTs were able to develop lessons that focused on the role of students in the lesson, the progression of students’ conceptions in the lesson, and the increased use of different models and modeling to engage students.

I adapted the PCK framework from Magnusson, Krajcik, and Borko (1999) to examine PTs’ PCK for MBI as manifested in their lesson and unit designs. My study focused mostly on the practices and epistemology connected to the PTs’ understanding of scientific models and modeling in science, as well as their knowledge of science teaching in designing and planning lessons. Knowledge of science teaching pertains to understanding how learning occurs and is facilitated in science curricula; achieving an understanding of students’ thinking, abilities, and conceptions; developing a repertoire of instructional strategies to engage learners; and designing assessments of science learning. In the next chapter, I discuss the methods that I used to conduct my study.
Chapter 3: Methods

3.1 Overview and Research Questions

In this chapter I describe the methods that I used in my qualitative research study examining 15 PTs’ developing knowledge of MBI and their ability to use this knowledge to design lessons. This chapter is organized into three sections: (a) research context and participants, in which I describe the PTs and the methods courses that they took as part of their teacher certification program; (b) data sources, including descriptions of each; (c) the data analyses; and (d) trustworthiness. Qualitative research methods allowed me to produce comprehensive, in-depth, and holistic descriptions of the growth in PTs’ knowledge of MBI and their ability to design lessons through multiple sources (educational philosophy papers, clinical interviews, lessons, and final reflection papers) that are meaning-rich (Merriam, 1988). Specifically, the following questions guided my study:

1. In what ways do PTs’ knowledge, as demonstrated through course assignments, of MBI develop over the four consecutive methods courses?

2. In what ways do PTs’ ability to design model-based inquiry lessons and units change over time?

3.2 Research Context and Participants

My study involved the 2006 cohort of 15 PTs (4 male and 11 female) enrolled in a two-year biological science certification program at a large university in the northeast U.S. This graduate program was geared towards two types of students—students that were juniors majoring in the biological sciences or a related field and seeking teacher
certification in (5-year undergraduate students), and students that had completed an undergraduate degree and were seeking certification (post-baccalaureate students). There were two tracks at this university for science certification—a physical science track to certify physics and chemistry teachers (Etkina, 2010) and a biological science track to certify biology teachers. In both tracks, all PTs had completed at least 30 credit hours in the subject matter (in this case, biology) before entering the teacher education program.

In this cohort of biological science PTs, one student had a Ph.D. in Biology, four had Bachelor of Science degrees in Biology/Biological Sciences, and ten were in their fourth year of a five-year Biological Science or related program (e.g. Animal Sciences, Ecology and Natural Resources, and Environmental Science). Two students had extensive research experience, one as a senior scientist, the other as a researcher/laboratory manager in commercial laboratories, and another two worked as research assistants at the college level during their undergraduate programs (see Table 1).

Table 1. Preservice Teachers

<table>
<thead>
<tr>
<th>Preservice Teachers (pseudonyms)</th>
<th>Post-Baccalaureate</th>
<th>Students in a 5-year Program (majors)</th>
<th>Teaching Experience (including tutoring)</th>
<th>Research Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christine</td>
<td></td>
<td>Animal Science</td>
<td>Summer camp</td>
<td>Undergraduate college research</td>
</tr>
<tr>
<td>Patrick</td>
<td></td>
<td>Biology</td>
<td>Tutoring</td>
<td>None</td>
</tr>
<tr>
<td>Jackie</td>
<td>B.S. in Molecular Biology</td>
<td></td>
<td>Teaching assistant in college</td>
<td>Undergraduate college research</td>
</tr>
<tr>
<td>Nina</td>
<td>B.S. in Biology</td>
<td></td>
<td>30 hours of teaching in high school</td>
<td>None</td>
</tr>
<tr>
<td>Jack</td>
<td></td>
<td>Biology</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Catherine</td>
<td>B.S. in Animal Science</td>
<td></td>
<td>None</td>
<td>Laboratory Manager</td>
</tr>
</tbody>
</table>
As part of the certification program, the PTs completed four subject-specific methods courses in consecutive semesters (Methods I–IV). Dr. Ravit Golan Duncan, my dissertation adviser, taught the four methods courses. I, together with two other graduate students, helped Dr. Duncan design the courses, taught parts of the courses (as teaching assistants), and collected and analyzed data from the courses. In Methods I, PTs engaged in MBI activities, readings, and discourse designed to promote their understanding of scientific inquiry and engender a view of science as theory-building. The goal of the various activities was to provide the PTs with experiences of inquiry from a learner’s perspective, and to provide a model of what MBI teaching looks like. For instance, PTs
developed naïve models regarding the formation of cancer. They made their models public, examined the different evidence (data and scientific journals) for and against their models, revised their original models based on new evidence, and formed a consensus model. These examinations and discussions became lengthy at times due to the complexity of the concept (cancer), differences in content background of PTs (in the field of molecular biology and about the topic of cancer), and challenges in understanding some of the journal articles. PTs also engaged in discussions regarding MBI in the classroom. These discussions included (a) thinking about student ideas, (b) anticipating students’ difficulties in learning a particular concept or skill, (c) analyzing evidence-based argumentation in classrooms (from videotapes of middle school classrooms engaged in MBI), and (d) assessing student learning (analyzing artifacts generated by middle school students engaged in MBI).

In addition to the inquiry activities, in Methods I, PTs also engaged in lesson critique and revisions—an important aspect of teacher preparation (Davis, 2006; Duncan, Pilitsis, & Piegaro, 2010). PTs critiqued three lessons based on a set of 5–7 criteria developed individually and then as a whole class. The PTs applied the criteria to lessons that were given to them and that reflected a continuum of less to more inquiry-oriented (the research team selected these lessons from books and the internet). Lesson critiques and revisions were designed to enhance PTs’ understanding of inquiry-based lessons and their design (Crawford, 1999; Duncan, Pilitsis & Piegaro, 2010; Schwarz & Gwekwerere, 2007).

A more intensive focus on lesson design was part of Methods II and Methods III. Methods II was essentially a design-based course in which the PTs, in small groups,
developed extended model-based inquiry units about selected topics in biology such as photosynthesis, ecosystems, etc. In this course, PTs were introduced to several design frameworks including Learning for Use (Edelson, 2001) and Backwards Design (Wiggins and McTighe, 2005). The design work involved several “milestones” and lasted the entire semester. These milestones included identifying appropriate learning goals, interviewing students to identify common prior conceptions, developing a problem context for inquiry lessons/units, and developing an entire set of lesson plans and assessments. At the end of this course, the PTs developed and implemented a single model-based inquiry lesson (lasting 1-2 days) in their observation placement classrooms. Lessons and activities in this course were scaffolded to increase PTs’ repertoire in analyzing students’ prior conceptions and alternative conceptions (Crawford, 1999), decision strategies involved in incorporating models and modeling in lesson design (Schwarz & Gwekwerere, 2007), incorporation of epistemological bases of scientific knowledge in lessons (Duschl & Wright, 1989; Windschitl & Thompson, 2006), and experience in teaching inquiry (Windschitl, Thompson, & Braaten, 2008).

In Methods III, PTs further developed their abilities to teach inquiry-based lessons and assess students’ thinking during their supervised student teaching internship, which lasted 15 weeks. In this course, PTs were given two opportunities to plan, implement, and critically examine extended model-based inquiry lesson sets. The first lesson set was done in weeks 4-7 and involved a 1-2 day inquiry lesson focusing on at least two model-based inquiry teaching strategies, while the second was done in weeks 10-14 and entailed a week-long model-based inquiry unit involving all the main elements of MBI. PTs also recorded their second lesson set and shared and discussed an excerpt of the video in the
seminar. As part of the assignment, PTs also critically analyzed student learning in the lesson sets and reflected on their plan and implementation, then recommended revisions to the lessons. This course provided PTs’ an opportunity to actually implement the pedagogical approach, MBI, which is at the core of the certification program.

The goals of the final course, Methods IV, were to develop the PTs’ skills as reflective practitioners, as well as to help them create a teaching portfolio that they could use in their job interviews. Specifically, PTs conducted action-research projects in which they analyzed data from their student teaching to address research questions about the MBI approach that they developed during Methods III, conducted a literature review, shared their results, and discussed instructional implications. PTs also developed teaching portfolios that included evidence of good instructional practices, an understanding of key learning theories in science instruction, and examples of students’ work. These activities aimed to additionally develop PTs’ knowledge of learners, MBI, and assessment. In summary, PTs engaged in understanding and experiencing MBI in Methods I, were immersed in lesson and unit design and implementation in Methods II and III, and engaged in reflection on their emerging MBI practices in Methods IV. Appendix A contains a more detailed description of the lessons, activities, and assignments in each of the four methods courses.

3.3 Data Sources

In order to capture changes in the PTs’ notions of MBI and its implementation on lesson design, I chose data sources (mostly course artifacts) that were relevant to issues
of lesson design. The data included educational philosophy papers, clinical interviews, lesson or unit designs, and final reflection papers, each of which is described below.

3.3.1 Educational Philosophy Papers.

In Methods I, PTs were asked to address four questions in a teaching philosophy paper: (a) “What are the goals of biology education and what should be taught in high school?” (b) “What are the problems with the current instructional methods?” (c) “What are the best ways to learn and teach science?” and (d) “Describe an ideal lesson in biology.” While the questions did not explicitly use the words “scientific inquiry,” PTs’ answers to the questions gave insights about their implicit notions of science inquiry in the form of investigations or experimentation (not MBI) as well as the characteristics of a good lesson. The philosophy paper was written as a homework assignment and was submitted the second week of Methods I (see Appendix B).

3.3.2 Clinical Interviews.

Clinical interviews were conducted with each teacher at the end of each of the four methods courses. I and the other graduate students conducted the majority of the interviews. The graduate students helped develop the interview protocol and were trained on using it by observing Dr. Duncan conduct an interview and then debriefing the process. Each interview was structured around a discussion/debriefing of a task central to MBI. The interview protocol had four tasks: (a) defining model-based inquiry, (b) critiquing a lesson, (c) designing a lesson, and (d) evaluating students’ written work examples (see Appendix D). My dissertation research involved analyses of the first and
third interview tasks in order to get a sense of PTs’ knowledge of model-based inquiry and their ability to develop inquiry-based lessons, respectively.

During the first task, PTs were asked to draw and explain a model of scientific inquiry as scientists conduct it, then identify challenges that students may have when engaging in similar scientific inquiry practices. During the third task, PTs were asked to design a lesson based on three objectives given to them. To reduce improvement on task due to familiarity with context, two comparable versions of this task were developed (one on photosynthesis and the other on cellular respiration) such that PTs received a different version in consecutive interviews. These versions were counterbalanced across PTs and across the four end-of-course interviews (PTs received alternate versions). Version A had three objectives for the topic of photosynthesis, while version B had similar objectives for the topic of cellular respiration. PTs described outlines of a 2-3 day lesson set that would address the provided goals. These design tasks lasted for about 15-20 minutes. Interviews were recorded using audio and video. All interviews were transcribed verbatim.

### 3.3.3 Lesson Plans

PTs were required, individually, to design lessons and units in Methods II, III, and IV. In Methods II, PTs were asked to design and implement a single model-based inquiry lesson (average length was for a 40-minute class period) in their observation placement classrooms (between weeks 10-12) as part of their Teaching Experiment I assignment. PTs were given a lesson plan template that they used to develop their own lesson. Required components of their lesson design included: (a) an overview of the lesson, (b) lesson objectives, (c) relevant student conceptions/anticipated alternative
conceptions, (d) relevant national and local science standards, (e) materials, (f) instructional activities that include at least one element of MBI (such as developing an initial model, using evidence to argue about competing models, or using evidence to revise a model), and (g) assessment (see Appendix F).

In Methods III, PTs individually developed and implemented two sets of detailed lesson plans. *Lesson Set I* was conducted between weeks 4-7 and *Lesson Set II* between weeks 10-14. Prior to implementation, PTs were asked to provide detailed lesson plans, which included the same components mentioned above. *Lesson Set I* focused on at least 2 aspects of MBI and was supposed to last 2-3 days, whereas *Lesson Set II* was supposed to encompass an entire MBI unit (about a week’s worth of instruction and a complete MBI process). Both sets of lessons were implemented and then critically analyzed through reflection. The PTs included suggestions for improvements for these lessons based on their reflections and analysis in the final assignment report. Finally, in Methods IV, each student was asked to revise one of the lessons taught during student teaching (in Methods III) based on the feedback they received from their course instructor and classmates, and their teaching experiences in Methods III that included interactions with students.

**3.3.4 Final Reflection Papers.**

PTs were required to write final reflection papers at the end of each semester to capture the changes in their notions of scientific inquiry and teaching approaches. Specifically, PTs were given three guiding questions to reflect on, each dealing with one of the following areas: (1) how their understanding of the nature of scientific inquiry
changed over the semester, (2) how their understanding of approaches to teaching science
developed, and (3) what concepts or topics they might still be unsure or confused about.
PTs submitted 2-3 typed pages electronically. I used these final reflections to triangulate
my analyses of the clinical interviews and lesson units/sets (see Appendix H).

3.4 Data Analysis

3.4.1 Educational philosophy paper.

The analysis of educational philosophy papers represented a pre-instructional
measure of PTs’ ideas about the best ways to teach and learn science, as well as the
components of an ideal lesson in biology. This baseline point of analysis gave me
insights into what PTs may or may not know about MBI and lesson design. Data analysis
for this task began with the identification of codes related to the general approach that
PTs identified as the best ways to teach and learn science (e.g. group learning, class
discussion, teacher lecture/demonstration, etc.) as well as their ideas about MBI, which
were limited to hands-on investigation and experimentation. I refined and applied these
codes to analyze PTs’ ideas of the components of an ideal lesson in biology. The
development of my coding schemes proceeded through an iterative process of application
to the data set and refinement of the codes to capture relevant emerging themes in the
data (Corbin & Strauss, 2008; Merriam, 1998). I double coded the data in instances when
a statement fit into two different categories. I present a complete list of categories and
examples of them in chapter 4, the “Findings” section of this document.
3.4.2 Semi-structured interviews.

Data analysis of the transcribed interviews started with analyses of the third task, lesson design. Before conducting my analyses, I blinded (removed names) and rearranged the transcripts from different methods courses to minimize bias. The first coding pass resulted in a list of the different activities in the lesson, such as teachers asking questions to gather students’ prior knowledge (naïve models), teachers delivering lectures and demonstrations, teachers voicing students’ ideas, hands-on experiments, etc. Through constant comparison of transcripts from interviews at different points in time, I was able to create categories and assign different levels to identify shifts in the nature and quality of teachers’ lesson designs with regard to:

(a) Student-centeredness of lessons
   a. level 0—teacher-centered
   b. level 1—partly student-centered
   c. level 2—student-centered
   d. PTs’ voicing student ideas

(b) Modeling
   a. level 0—no modeling
   b. level 1—script modeling
   c. level 2—modeling practice

(c) PTs’ conceptions about students’ knowledge
   a. vague or no conceptions
   b. facts, skills, and understandings
   c. learner’s history
After coding all lesson design from the interview transcripts, I identified trends in the categories and subcategories that I mentioned above from the different methods courses. The category *modeling* informed the PTs’ understanding and development of MBI in lessons (research question 1) while *student-centeredness of lessons* and *PTs’ conceptions about students* were categories that described the changes in teacher-developed lessons (research question 2) with respect to students. I describe and provide examples of each category and subcategory below.

### 3.4.2.1 Designing student-centered lessons.

The first category that emerged in my analysis of interviews was *student-centeredness of lessons* as I coded the PTs’ descriptions of their roles in the lesson, instructional activities (e.g. experiments, group work, etc.) and students’ tasks in the lesson. I counted instances in which PTs described lesson sequences that were teacher-centered (level 0), partly student-centered (level 1), and student-centered (level 2). I used the NRC’s (2000), *“Essential Features of Classroom Inquiry and Their Variations,* to guide me in developing my codes and creating the different levels. Specifically, I coded the lesson sequence as *teacher-centered* in instances in which the teacher provided information through lectures and demonstrations, the learner was prescribed “cookbook-type” investigations, the learner engaged in questions provided by teacher, or when the learner was provided with evidence and how to use evidence to formulate explanation.

I coded lesson sequence as *partly student-centered* (level 1) if PTs included students clarifying questions provided by teacher, students creating investigations or engaging in a guided investigation, or students being guided in the process of formulating explanation and evidence. These lessons were mostly teacher-based, as the teachers often
lectured, did not elicit students’ prior knowledge, and/or did not describe the anticipated outcomes of the investigations. In other words, lessons in level 1 included components that were both student- and teacher-centered.

With respect to *student-centered* (level 2) lessons, I coded and counted instances in which PTs included several (three or more) of the following components in their lesson design: (a) learner engages in scientifically-oriented questions, (b) teacher elicits students’ prior knowledge, (c) teacher addresses students’ prior knowledge, (d) learner develops or engages in an investigation, (e) learner gathers evidence and formulates explanation, and (f) learner communicates and justifies explanations. Moreover, within the *student-centeredness of lessons* category, I coded lessons in which PTs voiced students’ ideas and mimicked what they thought their students would say or ask during a given lesson. The *voicing student ideas* level reflected PTs’ knowledge and attention to students’ conceptions or experiences. Table 2 below lists examples for each of the subcategories within the *student-centeredness of lessons* category.

Table 2. Codes and examples for student-centeredness of lessons category.

<table>
<thead>
<tr>
<th>Codes for student-centeredness of lessons</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0—teacher-centered</td>
<td>“I want to give them more background information to get the point across that through respiration, glucose is broken down and that is energy, and just repeat that whole process of breakdown and energy.” (Molly, Methods I)</td>
</tr>
<tr>
<td>Level 1—partly student-centered</td>
<td>I will begin with a guiding question: “How can a redwood tree grow so tall?” Then I will ask them to create a naïve model to get their prior knowledge regarding the guiding question. I will then introduce an experiment of some sort about photosynthesis, plants, light, CO₂, probes to get CO₂. I will ask them to do an experiment of some kind that will show the changing of concentrations of O₂ and CO₂ by keeping the probes there to see</td>
</tr>
</tbody>
</table>
the changes and what is going on. From that they can analyze that data and make some charts to see the correlation between the different variables in the experiment. After that, I will have them share the results to the class... hopefully they are in [sic] the same page, but if not, I will end with a quick benchmark lecture to get everyone in the same page. (Nora, Methods III)

| Level 2—student-centered | So by starting with plants, you can get them thinking how they make their own food... and how do we get our energy? ... I would like to see their prior knowledge ... if there is no clear understanding and there is really no prior knowledge then I wouldn’t have them model... depending upon their prior knowledge... I know this sounds crazy but I would probably give them some experiments that scientists did to figure out how we get our energy... Like what they ate this for 20 minutes and they were fine or they ate this for 20 minutes and they didn’t feel well. So on and so forth. Then I would see if we added something to that prior knowledge... (Molly, Methods III) |
| PT’s Voicing student ideas | “I started asking the question [sic] “How do we get energy and how do we use it?” I am guessing all the kids will say we get energy from food. And then a million answers would be used it [sic] for running or something like that.” (Jack, Methods IV) |

3.4.2.2. Modeling.

In order to capture the nature and shifts in PTs’ knowledge of MBI in lessons from transcribed interviews, I created a second category that I called modeling, along with its own subcategories (level 0—no modeling; level 1 —scripted modeling; level 2—modeling practice). I used the EIMA (engage-investigate-model-apply) framework described by Schwarz (2009) to guide the development of my codes for modeling. Specifically, EIMA in the classroom entails: (a) engaging students in a question to elicit their prior conceptions, (b) helping students’ test their models through investigations, (c) helping students evaluate their evidence to explain and revise their models, and (d) engaging students in argumentation. Within modeling, I counted instances in which a lesson did not include student modeling (designated as level 0). At this stage, PTs did not elicit students’ ideas, recognize these ideas in their lessons, or have students revise pre-
conceptions based on investigations. The second subcategory of modeling was *scripted modeling* (level 1). It involved instances in which PTs included the language of modeling in their lessons; however, the modeling process was prescriptive or procedure-oriented and it did not mention student models. Finally, *modeling practice* (level 2) tied in the process of modeling with the target concepts and anticipated student models. Table 3 lists the codes with examples at the different levels of modeling in lessons.

Table 3. Codes and examples of modeling

<table>
<thead>
<tr>
<th>Codes for modeling</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0—no modeling</td>
<td>“I would say if light is involved then it needs to be some type of activity to exclude light. Then photosynthesis produces glucose and starch, so this absence or presence of light would be the only variable to produce/not produce glucose. So run a test to detect starch. Well, building up oxygen again could be something—I am just trying to think of simple experiments to measure the oxygen.” (Nadia, Methods I)</td>
</tr>
<tr>
<td>Level 1—scripted modeling</td>
<td>With the initial model, maybe students would be a little to set to stick with their initial model. They should probably after research, after experiment be ready to develop a new model ... All the while this research and experimentation should be in a group. It doesn’t have to be a big group. Just so that students don’t wonder off. They are sticking in a group talking to people. They are sharing ideas. And that’s it. (Patrick, Clinical Interviews, Methods I)</td>
</tr>
<tr>
<td>Level 2—modeling practice</td>
<td>After the group model is done, I would have them each group present to the class, post them around the room, and then we would engage in classroom argumentation to see what the differences were and to see if we could reach a class consensus. The models should contain all three of these aspects: how plants get and convert energy—that would be if they put the nutrients chlorophyll and light; equations—inputs and outputs and using glucose as a source of energy. I would require them to somehow explain the end results. (Sean, Clinical Interviews, Methods III)</td>
</tr>
</tbody>
</table>
3.4.2.3 *Presevice teachers’ knowledge about students.*

The third and final category that I created for the third task of lesson design from interviews was *PTs’ conceptions about students’ knowledge.* This category included the extent to which PTs’ mentioned ideas about their students’ prior conceptions, understandings, skills, potential difficulties, alternative conceptions, and learners’ history. Within the category of *PTs’ conceptions about students’ knowledge*, I coded and counted instances in which PTs demonstrated: (a) vague or no conceptions, (b) conceptions about facts, skills and understandings, (c) and conceptions about their learners’ history. I adopted these coding schemes from the work of Gullberga, Kellnera, Attorpsa, Ithore’ña and Ta’rnebergb (2008) regarding PTs’ conceptions about students’ knowledge and beliefs about science and mathematics in Sweden. The coding of *vague or no conceptions* pertains to instances in which PTs failed to explicitly describe what students knew or did not know about the big idea in the lesson. I coded *facts, skills, and understandings* in instances in which PTs mentioned explicitly what students know, do not know, or are able to do, including possible difficulties and/or alternative conceptions. The *learner’s history* subcategory included PTs’ descriptions of lessons or concepts that students may have known or learned before engaging with a particular topic. These lessons contained careful sequencing of activities with respect to science content and scaffolding of students’ prior knowledge. Table 4 below contains examples for each code.

Table 4. Codes and examples for PTs’ conceptions about students

<table>
<thead>
<tr>
<th>Codes for PTs’ conceptions about students</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vague or no conceptions</td>
<td>“And then (reads lesson plan silently) I guess I would want to go over the process of respiration with them, but I don’t know the background and what was covered.” (Molly,</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Methods I)

<table>
<thead>
<tr>
<th>Facts, skills, and understandings</th>
<th>“I don’t know what grade level this would be; they might know that air is made out of different kinds of molecules.” (Christine, Methods I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learner’s history</td>
<td>“Usually, by photosynthesis they have had atoms, molecules, and energy in the chemistry section but review that a little bit, and I would even go so far as to explain pigments. It is hard to say how far because you don’t know what came before this lesson but I know in our curriculum they would already know what a protein is and proteins are targeted for certain molecules.” (Christine, Methods III)</td>
</tr>
</tbody>
</table>

My analyses of the interviews informed the analyses of the lessons and the final reflection papers, which are described in the next sections.

3.4.3 Lessons.

Data analysis of lesson designs was guided by the categories that emerged from the analysis of the lesson-design task of the interviews—student-centeredness of lessons, modeling, and PTs’ knowledge of students. Analysis of lesson designs focused on examining each component of the lesson plan (see Appendix F) with respect to PTs’ abilities in designing science lessons based on the teachers’ PCK in MBI (Magnusson et al, 1999; NRC, 1996), PCK of students’ thinking and understanding in the domain (Michaels et al., 2008; Schwarz, 2009), PCK of relevant instructional strategies (Etkina, 2010; Schwarz & Gwekwerere, 2007), and assessment. Data analysis began with the coding of lesson sets in Methods II through Methods IV, the creation of hierarchical levels (e.g. lesson objectives reflect a big idea in science, productivity of the driving question, science practices, PTs’ knowledge of students’ prior conceptions), and the refinement of these codes through an iterative process with respect to the following categories:
1) Goal orientation and objectives

   a) Reflect big ideas in science
   b) Measurable and performance-based objectives
   c) Goals are aligned with standards

2) Productivity of the driving question

   a) Level 2— the driving question will elicit relevant prior conceptions (productive)
   b) Level 1— the driving question will elicit relevant as well as irrelevant prior conceptions (semi-productive)
   c) Level 0— the driving question will not elicit relevant prior conceptions (not productive).

3) Methods or instructional activities

   a) Use of evidence in lesson design
   b) Scientific practices

4) Assessments

5) PT’s understanding of students’ prior knowledge

   a) PTs’ knowledge of students’ potential difficulties with and alternative conceptions of the topic
   b) Leverages

Analyses of patterns in these codes through different points in time allowed me to identify shifts in PTs’ knowledge of MBI and its implementation in lesson design. In particular, the methods or instructional activities contained descriptions of the different science practices in the lesson sets that reflected PTs’ ideas about modeling, argumentation, and investigations. I used this to observe the changes in PTs’ knowledge of MBI that were reflected in lesson sets (research question 1). In addition, I used the goal orientation and objectives, driving question, methods or instructional activities, and assessments categories to describe the shifts and nuances in designing inquiry-based lessons (research question 2). Finally, the category of PTs’ understanding of students’ prior knowledge mapped changes in the lesson design with respect to PTs’ attention to
the learners (research question 2). I describe and provide examples for each of the
categories and subcategories in the sections below.

3.4.3.1 Goal orientations and objectives.

Subject matter knowledge is essential in selecting appropriate goals and
objectives to guide students’ content learning experiences around the science concept in a
given lesson (Gess-Newsome & Lederman, 1999). Within the goal orientation and
objectives category, I coded the extent in which the PTs’ identified goals reflected the
“big ideas” in science. I used the Big Idea Tool developed by Windschitl, Thompson, and
Braaten (2011) in developing and defining my codes. According to Windschitl et al., “big
ideas are about the relationship between some class of natural phenomenon and a causal
explanation that helps us understand why that class of phenomena unfolds the way it
does” (Big Idea Primer, p.1). An example of a phenomenon of interest may involve
students’ comparing and contrasting their own physical appearance with that of their
parents. One way to describe this big idea is to demonstrate that parents’ alleles are
randomly combined when sperm and egg combine to make a baby; hence, the baby has
combination of alleles from their parents. Within the goals reflect big ideas in science
category, I identified four different levels: (a) level 0—does not include a big idea, (b)
level 1—includes big ideas but lacks reference to a mechanism, and (c) level 2—
indicates a big idea in science with a causal explanation or mechanism. Table 5 below
lists the levels and examples that I used in the analysis.

Table 5. Different levels for the goal orientation and objectives reflect big ideas in
science category

<table>
<thead>
<tr>
<th>Level descriptions</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2—Lesson</td>
<td>“Students will be able to explain that a typical virus is composed</td>
</tr>
</tbody>
</table>
goals include big ideas in science with causal mechanism of a core of either DNA or RNA, surrounded by a protein coat, or capsid. In a lytic infection, virus enters a cell, makes copies of itself, and causes the cell to burst; in a lysogenic infection, a virus embeds its DNA into the DNA of the host cell and is replicated along with the host cell’s DNA.” (Nadia, Teaching Experiment Lesson Plan 1, Methods II)

| Level 1—Lesson goals include big ideas in science but lack mechanism | “Students will engage in scientific argumentation. They will learn the importance of photosynthesis for maintaining the food chain. Students will compare two plant cells from different organisms.” (Sean, Teaching Experiment Lesson Plan 1, Methods II) |
| Level 0—Lesson goals do not contain a big idea in science | “Have the students gain an understanding of why a scientist is a scientist. How a scientist gets the name of being a scientist. Learn a few different discoveries of Galileo, which made him be [sic] a very important scientist.” (Molly, Teaching Experiment Lesson Plan 1, Methods II) |

In addition to the big ideas in science, I also analyzed whether or not the goals and objectives in the lesson were measureable and performance-based. Identifying and defining appropriate goals and objectives are important tasks because they provide direction in the lesson. To capture the sophistication of objectives provided by PTs in their lessons, I analyzed whether the objectives were performance-based or not, as well as whether the objectives were higher- or lower-level objectives based on Bloom’s *Taxonomy of Educational Objectives—Cognitive Domain* (1956). The objective is performance-oriented when the performances are concrete, explicit, and can be measured (e.g. students will be able to explain, calculate, create, and differentiate). Moreover, investigation, ability to explain, and the content of explanation are student enactments that a teacher can use to assess and evaluate students’ learning. On the other hand, terms such as *students will know and understand* in lesson objectives are not observable or measurable. In addition, I used Bloom’s *Taxonomy* (1956) to guide the development of my coding schemes and count the number of higher-level and lower-level objectives. Lower-level objectives require students to recall data or information (e.g. define,
describe, identify, label, select), while higher-level objectives ask students to comprehend, apply, evaluate, and synthesize the material (e.g. analyze, predict, interpret, compare).

Table 6. Types and levels of objectives

<table>
<thead>
<tr>
<th>Types of objectives</th>
<th>Levels of performance</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance-based</td>
<td>Higher-level</td>
<td>“Students will be able to apply the cell theory to explain the structure and function of cells.” (Christine, Lesson Set 1, Methods III)</td>
</tr>
<tr>
<td></td>
<td>Lower-level</td>
<td>“Students will be able to describe the balances of an ecosystem and locate where the balance is disrupted when an invasive species is introduced” (Jackie, Teaching Experiment Lesson Plan 1, Methods II)</td>
</tr>
<tr>
<td>Not performance-oriented</td>
<td></td>
<td>“Students will know that there are four nitrogenous bases (Adenine (A), Thymine (T), Guanine (G) and Cytosine (C)) and understand that phosphate and sugar make up the backbone of DNA” (Nina, Teaching Experiment Lesson Plan 1, Methods II).</td>
</tr>
</tbody>
</table>

Finally, I analyzed the extent to which the lesson goals and objectives were aligned with the local and/or national science education standards in the following ways: (a) level 2—goals were adequate and fully aligned with standards, (b) level 1—lessons contained irrelevant or missing standards, and (c) level 0—lessons do not have standards or not aligned. Table 7 below lists the levels and examples that I used in the analysis.
Table 7. Different levels for alignment with standards

<table>
<thead>
<tr>
<th>Levels</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Level 2—adequately aligned | New Jersey Core Curriculum Content Standards (NJCCCS) for Science  
5.5.12 A. 4. Relate disease in humans and other organisms to infections or intrinsic failures of system.  
5.1 A. 1. When making decisions, evaluate conclusions, weigh evidence, and recognize that arguments may not have equal merit.  
5.1 A. 3. Engage in collaboration, peer review, and accurate reporting of findings.  

Lesson Overview:  
The students will be presented with the viruses as separate entities of a living world, their structure and function, and how viruses interact in the environment, causing an infection and a disease. Activities are all based on modeling, forming hypotheses, testing them by finding supporting or refuting data, generate evidence and revise models based on that. Students are provided with handouts of scientific data that they can use to test their ideas. First, students will watch a short animation of a virus, without any indication what it is. The question what this is and then what makes a virus will elicit their initial ideas and reveal their thinking. The teacher will ask students what is similar and what is different between viruses and bacteria and build a compare/contrast diagram bacteria vs. viruses based on students ideas. All ideas and a diagram will be documented on the whiteboard and used to build a class naïve model of a virus. With data provided in handouts as authentic data for HIV virus, the students will be able to test their hypotheses and revise their models, working in pairs. In the second part of the lesson, the students will watch another short video about myths versus scientific evidence in HIV/AIDS. The question “how does HIV cause a disease’ will lead into building a naïve model as a class, and with data provided in handouts, students will work in groups and develop (revise) their naïve class model into a more scientific one, and prepare it on a poster for presentation to the class. In the end, students will present models in class and discuss each other’s models. They will agree on the class consensus model about ‘How does HIV cause a disease’. (Nadia, Teaching Experiment Lesson Plan 1, Methods II) |
| Level 1—missing or irrelevant standards | NJCCCS 5.5 (Characteristics of Life) All students will gain an understanding of the structure, characteristics, and basic needs of organisms and will investigate the diversity of life.  
[Note: Missing standards on science practices.] |
3.4.3.2 Productivity of driving questions.

In order to capture the sophistication of the driving questions in lessons, I coded and created three levels for the productivity of the driving question: (a) level 2—the driving question will elicit relevant prior conceptions (productive), (b) level 1—the driving question will elicit relevant as well as irrelevant prior conceptions (semi-productive), and (c) level 0—the driving question will not elicit relevant prior conceptions (not productive). The driving question was coded as productive (level 2) if it could potentially activate students’ prior learning and experiences including alternative conceptions, concepts that were difficult for students to learn, and concepts that they did not know. On the other hand, level 1 driving questions could elicit both relevant and irrelevant student pre-conceptions because they might be too broad. Finally, driving questions might not elicit relevant prior conceptions (and thus be coded at level 0—not productive) due to how the question was worded (syntax or vocabulary) or would only illicit irrelevant prior conceptions.

Table 8. Productivity of the driving questions to elicit students’ prior conceptions

<table>
<thead>
<tr>
<th>Levels of productivity</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Level 2—productive     | “The students will draw on the knowledge that they have from previous lessons, of what they know about viruses from newspapers, TV, family talks, and the earlier class discussion ….The teacher will encourage their thinking and elicit their ideas by asking questions: ‘Are they a life form?’, ‘What defines life?’, ‘Do they have cells?’…in order to lead them into thinking about growth (do they
metabolize, do they contain proteins), reproduction (do they carry genetic information), do they have membrane (like cells), how do they obtain energy, do they ingest, excrete?’” (Nadia, Teaching Experiment Lesson Plan 1, Methods II).

<table>
<thead>
<tr>
<th>Level 1—semi-productive</th>
<th>“Begin the lesson by asking students what they know about viruses. It’s a general question that most of the students should have some input into” (Jack, Teaching Experiment Lesson Plan 1, Methods II).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0—not productive</td>
<td>“[individual students] will draw/write their ideas of examples of biomolecules worksheet 1.1 (5min)” (Catherine, Lesson Set I, Methods III).</td>
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</table>

### 3.4.3.3 Methods or instructional activities.

The third component of the lesson that I analyzed was the methods or instructional activities, in which PTs described the procedures of instruction selected to address the lesson goals. In a lesson plan, the methods or instructional activities section, in which teachers describe what they intend to do in the lesson (e.g. classroom investigation, group work, lecture, presentation, etc.) is usually situated in between the driving question and the closure. In order to capture differences in the complexity and changes over time of the instructional activities described by the PTs in their lessons, I coded, counted, and created different levels under the category of science practices. These practices included modeling (level 2A), argumentation (level 2B), experiment-driven or experiment-based without modeling (level 1), and teacher-centered lecture and demonstrations (level 0).

Argumentation is part of the scientific modeling process in which students use evidence from experiments or reputable sources (e.g. published journals, experimental data) to defend or refute a model. The second subcategory under science practices is modeling (level 2A), in which PTs describe the modeling process (naïve modeling,
investigations, revised modeling) that they intend to include in the lesson. Modeling and argumentation are both important components of MBI. In order to capture the complexity of the different processes or combinations of scientific modeling described by PTs in the lessons, I color-coded and counted the instances of the following sub-categories: (a) naïve modeling or eliciting students’ prior conceptions only (turquoise), (b) naïve and revised modeling (pink), and (c) evidence or data provided to students (red). Table 9 lists the components of the modeling process as well as examples that I used in my analysis.

Next, I coded the instructional methods as experiment-based (level 1) if the lesson had some form of an investigation, but did not include modeling. These were instances in which instructions were based on an investigation or some group activity that occurred without eliciting students’ preconceptions and capturing changes in their models after the instruction. Finally, I coded and counted the instances in which PTs provided a teacher-centered lesson (level 0). These were instances in which the teacher provided information through lectures and demonstrations, the learners engaged in questions provided by the teacher, and the teacher provided evidence and how to use evidence to formulate explanation. Table 9 below lists the levels and examples that I used in the analysis.

Table 9. Variations of scientific practices in lessons

<table>
<thead>
<tr>
<th>Different levels of scientific practices</th>
<th>Sub-categories</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2B—Argumentation</td>
<td></td>
<td>“Have the students post their revised models around the classroom so that each model can be seen. Ask the groups to present their revised models to the class one at a time. After each revised model is presented, allow the other students to ask questions and engage in argumentation about differences in the models.”</td>
</tr>
<tr>
<td>Level 2A—modeling</td>
<td>Using their revised models, the evidence from the simulations and their own argumentations, guide the students in the creation of a class model (you may draw on the board or you may assign a student or two to do so)” (Jackie, Lesson Set I, Methods III).</td>
<td></td>
</tr>
<tr>
<td>Naïve modeling only</td>
<td>“Make a list on the board of possible solutions for this problem. While still in groups, ask students to have them hypothesize and model what they think the impact is with the new species in town and the impact of implementing one of the possible solutions. Discuss their modeled solution as a class. What are the pro’s and con’s [sic] for each?” (Christine, Teaching Experiment Lesson Plan 1, Methods II)</td>
<td></td>
</tr>
<tr>
<td>Naïve and revised modeling</td>
<td>“Begin the class by asking the students what they know about water. Because the question is so general you should get answers that are both science related and trivia related. These should be made public on the board and these answers can lead into the slide presentation. After the mini lab, have students revise and explain their models of how trees take up water. Have the students present their model to the class and eventually form a class model that best depicts the process.” (Jack, Lesson Set 1, Methods III)</td>
<td></td>
</tr>
<tr>
<td>Evidence provided to students</td>
<td>“Once the slides have been presented ask the students to get into groups of three or four. Present each group with the worksheet which sets up the problem. The problem asks how it is possible for redwood trees to take up almost 4 tons of water 250 feet up to their leaves each day. The information they are given shows them that trees use tubes called xylem to take water up into their leaves. There is a microscope picture of xylem provided. Also the worksheet states that leaves on the top of the tree are much smaller and sparser than leaves that are closer to the bottom. Ask the students to model out and explain a way for the redwoods to take in all the water they need.” (Jack, Lesson Set 1, Methods III)</td>
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</table>
| | Demonstrate how to prepare the slides (including how to carefully peel a thin portion of onion skin). Pair students up, and instruct them each to obtain Handout D (“Laboratory Report Sheet:
Level 1—experiment-based

Comparing Elodea and Onion Cells’) and bring one microscope per pair to their lab benches. They may then approach your lab bench, where you will give each pair an elodea sprig; onion peel, pipette, and two slides with cover slips...Instruct them to follow the procedures written on Handout D. After a few minutes (after is becomes evident that most students have viewed the elodea leaf under 400X magnification), guide the students to understand that the small circles they are viewing are the chloroplasts. (Sean, Teaching Experiment Lesson Plan 1, Methods II)

Level 0—teacher-centered

“Once they have completed the Do Now you will begin a discussion on the answers in their do now. Record answers on the board, and help the students to pick up on the different patterns seen within their answers. Help lead the students toward the idea of experimentation and how scientists without the technology we have today were able to discover things. Begin to introduce Galileo and his many discoveries. The PowerPoint will address each discovery slowly and also pose questions to the students about how he may have possibly discovered these things, how he went about discovering these things. Have the students take notes as you go so that Galileo is in their notes” (Molly, Teaching Experiment Lesson Plan 1, Methods II).

In cases where experimentation was not feasible in a classroom setting due to time or resource constraints, PTs provided evidence or data for students to use/analyze in the lesson as an investigation. In order to capture the quality of evidence provided by PTs in the lesson and in order to describe their successes or struggles in selecting or creating evidence, I generated three levels: (a) level 2—evidence provided is specified and adequate for students to learn the big idea, (b) level 1—evidence provided is specified but not suitable or inadequate for students to learn the big idea, and (c) level 0—evidence is not specified, not suitable, or inadequate.
I coded evidence as suitable, specified, and adequate for learning the big idea (level 2) when data provided was suitable for students’ age, ability, and reading level (in terms of syntax and vocabulary); the information was sufficient and not overwhelming; and the information was adequate for learn the objectives. Next, I coded evidence as level 1 in instances when the evidence provided to students was specified but not suitable or inadequate for students to learn the big ideas. At this stage, evidence was either spoon-fed to students or was too complicated. Finally, I coded evidence as level 0 in cases where data was not specified, not suitable, or inadequate for students to learn the lesson objectives. The evidence was not suitable for students because it was too complicated for students’ age, ability, and reading level, or was potentially overwhelming.

Table 10. Suitability and adequacy of evidence in lesson design

<table>
<thead>
<tr>
<th>Suitability and adequacy of evidence</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2—data is specified and adequate</td>
<td>“For this activity, have students work at lab tables in groups of about three or four. Give to each group the twelve prepared index cards with historical events listed on them (but not including the dates of these events). Inform them that it is their task as individual groups to put these events in order from oldest to most recent. Walk around the room to question and aide [sic] students as necessary. When the students have made their final decisions, ask groups to share their order of events. Have the class engage in classroom argumentation in order to smooth discrepancies (encourage them to use reason and prior understanding to come to a consensus)” (Sean, Lesson Set I, Methods III).</td>
</tr>
</tbody>
</table>
“Separate the class into three groups and identify them as the tree experts, the bug experts and the predator experts. Give each of the group [sic] background information on their topic and ask them to extract answers to specific questions onto index cards. The students will be given all necessary information to establish a working ecosystem in China and North America” (Christine, Teaching Experiment Lesson Plan 1, Methods II).

“The teacher will ask students to pair, and will distribute worksheets and handouts with data about HIV virus – where it’s found and its components (electron micrograph of a host lymphocyte cell harboring viruses with clearly indicated size, EM of isolated HIV particles from blood, RNA and protein analysis, action sites of antiviral drugs). The students will be asked to make their model of a virus and explain it. The teacher distributes handouts with data about the qualitative and quantitative testing of HIV, blood cell counts, parallel tests for bacteria, and evidence that the infected lymphocytes get destroyed by healthy lymphocytes and macrophages in patient’s blood” (Nadia, Teaching Experiment Lesson Plan 1, Methods II).

3.4.3.4 Assessments.

The fourth component of the lessons that I analyzed was the assessments. In this section, PTs described the different strategies or forms of assessment (formative, summative) that they planned to use to assess students’ learning. I coded assessments as level 2 in instances when the assessments were relevant to the objectives, included formative or summative elements, and provided sufficient detail about the content and practices being assessed. Level 1 consisted of assessments that were relevant to the objectives, but were not comprehensive (focused simply on factual knowledge or
vocabulary) or lacked details. Finally, I coded level 0 for lessons that did not have assessments.

Table 11. Assessments

<table>
<thead>
<tr>
<th>Levels of assessments</th>
<th>Examples</th>
</tr>
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</table>
| Level 2—comprehensive | Assessed will be artifacts that students produce (embedded formative assessment) during the model-based inquiry lesson in a form of:  
  ▪ their models (activity 3: individual worksheet Model of What is a virus - understanding of content, scientific practice: modeling);  
  ▪ Arrow diagram (activity 6: individual worksheet Strength of evidence – comparing evidence from two models, scientific practice: argumentation, NOS: evidence changes models and theories). (Nadia, Teaching Experiment Lesson Plan 1, Methods II) |
| Level 1—insufficient information | Assessment  
  ▪ Participation during class and group discussion. Teacher should observe misuse and confusion of terms such as chromosome, gene, allele, phenotype and genotype.  
  ▪ A quiz will be administered, similar to the dihybrid cross worksheet, to assess Mendelian genetics, including monohybrid and dihybrid crosses as a whole. (Patrick, Teaching Experiment Lesson Plan 1, Methods II) |
| Level 0—no assessment | (Jack, Teaching Experiment Lesson Plan 1, Methods II) |

3.4.3.5 Preservice teachers’ conceptions of students’ prior knowledge.

I then analyzed the PT’s knowledge and considerations of what their students were likely to know, understand, be able to do, or could potentially struggle with in the lesson, which I coded as PTs’ conceptions of students’ prior knowledge. PTs described, in various ways, what science concepts their students might struggle with, what skills that they might lack, and what alternative conceptions they might have. I created different levels (level 2—comprehensive; level 1—brief or insufficient; and level 0—no idea or not mentioned) to capture PTs’ knowledge, and counted instances of each level to identify
shifts in various lessons designed at different points in time. *Comprehensive* (level 2) means that PTs’ indicated with sufficient detail what students know, don’t know, might struggle with, and/or students’ alternative conceptions. I coded the PTs’ knowledge as *brief or insufficient* (level 1) in cases where their descriptions were vague or lacked detail, and *not mentioned* (level 0) in instances in which PTs failed to indicate what they understood about students’ prior knowledge. Table 12 below lists the levels and examples that I used in the analysis.

Table 12. PTs’ knowledge of students’ potential difficulties and alternative conceptions

<table>
<thead>
<tr>
<th>PTs’ knowledge of students</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2—Comprehensive</td>
<td>In a paper by Martin Braund (1998), <em>Trends in children’s concepts of vertebrate and invertebrate</em>, he studied 3rd-10th graders concept knowledge of differences between invertebrates and vertebrates in grades (112). He found that 10th grade students think organisms such as fish, tortoises, and snakes are not vertebrates, because of how they move or in the case of the tortoise, that it has a shell (115). The secondary students who did understand that these organisms were vertebrates were recalling knowledge obtained outside the classroom (114). Braund suggests that all students should be working at the level of these students with outside generated knowledge, through pictures, videos, and working with animals in the classroom (114-5). During the identification part of the lesson, make sure to include pictures of fish, snakes, and turtles, just to make sure the students are clear that these are also vertebrates. (Catherine, Teaching Experiment Lesson Plan 1, Methods II)</td>
</tr>
<tr>
<td>Level 1—Brief or insufficient</td>
<td>In their introduction to Mendelian genetics, students learned topics of Mendel’s experiments, the law of segregation, the law of independent assortment, probability rules, genes, alleles, gametes, dominant and recessive, and the monohybrid cross…Students appeared, in class discussion and review, to have some confusion about the difference between alleles, genes, gametes. The lesson on dihybrid crosses should build using the same models the class developed for creating monohybrid crosses. (Patrick, Teaching Experiment Lesson Plan 1, Methods II)</td>
</tr>
<tr>
<td>Level 0—No idea or not mentioned</td>
<td>Students have already established the definition of an ecosystem. They have been introduced to the parts and</td>
</tr>
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</table>
‘balances’ in an ecosystem. This lesson will focus on invasive species and how they disrupt an ecosystem. This lesson could be followed with a lesson on environmental policy, by endangered species, or by other examples of ecosystems that are impacted by invasive species. (Christine, Teaching Experiment Lesson Plan 1, Methods II)

Finally, within PTs’ understanding of students’ prior knowledge, I analyzed instances in which PTs described leverages to anchor students’ new learning experiences. Leverages included PTs’ identification of students’ prior learning history as well as knowledge and skills. For instance, Patrick enumerated concepts that students learned in the previous lesson that he would use as leverages for the current lesson:

In the previous lesson students were introduced to the basic concepts of medallion genetics. Prior to beginning this lesson students should be sufficient at using monohybrid crosses to determine patterns of genetics inheritance. In this lesson they will be introduce to using a dihybrid cross, to predict the variation in mating individuals which differ in two different traits.” (Patrick, Teaching Experiment Lesson Plan 1, Methods II)

I also created three levels (level 2—comprehensive, level 1—brief or insufficient, and level 0—no idea or not mentioned) to capture the different degrees of leverages described by PTs in their lessons. Table 13 below lists the levels and examples that I used in the analysis.

Table 13. Identification of potential leverages in lessons

<table>
<thead>
<tr>
<th>Levels of leverages</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2—Comprehensive</td>
<td>I did a clinical interview of high school freshmen on the subject of mitosis although we didn’t get into DNA replication they did have an understanding that DNA is copied and separated from one cell into two cells that were genetically the same. This might play a role in helping them understand that viruses use this process to copy their own DNA and reproduce. (Jack, Teaching Experiment Lesson Plan 1, Methods II)</td>
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</table>
As this is at the end of the unit chapter, students should have an understanding of the subject. Some of the topics have been covered briefly in other units such as parts of the Mid-Atlantic Ridge and some of the organisms found in the ocean. These can be used to build upon and help relate what is going on the sea floor to what they have learned about the ocean at shallower depths. (Ava, Teaching Experiment Lesson Plan 1, Methods II)

| Level 1—Brief or insufficient | Students may have prior ideas of what these tissues are since students were required to take biology as a prerequisite to Human Anatomy and Physiology. Students may know the different shapes of the cells but may be unable to identify the name and location where they can be found. Students should have a grasp on the microscope, its parts, its functions and how to correctly use one for lab. (Nora, Lesson Set I, Methods III) |
| Level 0—No idea or not mentioned | In this lesson, students will encounter demonstration that center around the concept of diffusion. They will experience diffusion then define their experience in their own words. They will make educated predictions of the movement of particles across a membrane based on their experiences. (Christine, Revised Lesson, Methods IV) |

3.4.4 Final Reflection Papers.

The coding of the final reflection papers was guided by the categories that emerged from my analyses of clinical interviews and lesson sets. Specifically, my analyses focused on PTs’ reflections in four areas: (a) model-based inquiry, (b) different components of lessons, (c) student-centeredness of lessons, and (d) the difficulties and challenges associated with designing MBI lessons. Within the area of model-based inquiry, PTs described how they learned the modeling process; their experiences in designing experiments for students; collecting, identifying, and developing evidence as part of investigations; and argumentation. In terms of the different components of the lessons, PTs reflected on goals, driving questions that will elicit relevant students’ prior knowledge, goals that contained a big idea in science, a different view of the lesson
sequence from lecturing to hands-on learning and student engagement, and assessments that included student models. With regard to student-centeredness of lessons, PTs reflected on accounting for students while designing lessons by eliciting, addressing, and assessing students’ conceptions (including alternative conceptions). Finally, I coded the challenges with MBI, lesson design, and attending to students that PTs mentioned in their reflection papers. These included time constraints on MBI in the classroom due to standardized testing and district curricula, teaching and learning through modeling, difficulties in designing or adapting suitable and appropriate investigations or evidence for students, aligning assessments with the lesson, and anticipating and addressing students’ alternative conceptions. Analyses of the reflection papers were used to support my findings from the analyses of clinical interviews and lesson sets, which in turn addressed my research questions on PTs’ knowledge of MBI and its implementation on lesson design. Table 14 below lists the categories and examples from my analysis.

Table 14. PTs’ reflections on MBI and lesson design

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model-based inquiry</td>
<td>Inquiry begins with a question of interest. This question is most likely posed by the teacher. Following ‘interest’, the students begin to brainstorm and publicly acknowledge their thoughts on the topic. Students can then work in small groups to design a model of how they believe the system works. By using the model, the students should be able to develop a hypothesis. The model and hypothesis together should help the students design an experiment… The evidence from the experiment could justify your original model or it could refute your original model… These class discussions are a type of scientific argumentation. With all of the evidence and feedback a final, revised model can be created by the class.” (Nina, Final Reflection Paper, Methods I)</td>
</tr>
<tr>
<td>Components of</td>
<td>Now that I have taken this class, I have a new idea of what is characterized as a good science lesson. To start off, I would begin with posing a question or having my students observe phenomena. I would...</td>
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</table>
then have a discussion about what they think about the phenomena and their prior knowledge. Having the prior knowledge addressed I would have the students break up into groups and prepare to model their ideas together (seeing that models are shown to promote knowledge building communities)... I would then have the students develop experiments that would test their models. After performing these experiments, data could be analyzed and evidence can start to form... The evidence generated from the experiments would be used to justify claims made in their explanations of their models. These new revised models can be publicized once again to the class and argumentation can take place. (Nora, Final Reflection Paper, Methods I)

<table>
<thead>
<tr>
<th>Students</th>
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<tr>
<td>I find it difficult and challenging to predict how the students will react, how to leave enough ‘room’ for changes (maybe always having an alternative plan in case if...). In my experience it is essential to know where the students ‘stand’ at all times, but right in the beginning it is absolutely essential...Finding out students’ previous knowledge and ideas are essential for lesson planning!!!! For example, I should have taken in more consideration that my students already knew a lot about the cell structure and function, although the later in a very vague and fuzzy way, not really connecting them properly. There was a lot of factual knowledge already present, but not connected into a mechanism(s), and not deepened to causes/effects and higher implications of the existence of cells. (Nadia, Final Reflection Paper, Methods III)</td>
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<table>
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<tr>
<th>Difficulties and challenges</th>
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<tr>
<td>While writing this reflection it has become apparent to me that I need help when deciding what type of evidence and data is appropriate to give the students. Some data may be too simple and the students may not be able to connect the data to the question. Other data may be so complex in their eyes that they give up after viewing it for a few minutes (a few minutes of viewing before giving up would actually be nice! Usually they give up after 10 seconds!). How do I know what data is appropriate for students? And when the students do not understand the data how much help should I give them? (Nina, Final Reflection Paper, Methods II)</td>
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<tr>
<th>3.4.5 Statistical Analysis.</th>
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<tr>
<td>In order to determine the correlation and the significance of various numerical scores or counts obtained from my coding of the clinical interviews and lesson sets in the different methods courses, I calculated the Spearman’s rank correlation coefficient or Spearman’s rho (two-tailed at a confidence level of 95%) of the different categories in</td>
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</table>
lesson design. I used Spearman’s rho because (a) of the small sample size; (b) my data did not follow a normal curve distribution, which is the underlying assumption in using a more classical method such as a Z-test or Pearson correlation coefficient; and (c) my data consisted of ranked variables (from level 0 to level 2 or 3), which is the underlying assumption in using nonparametric statistics (McDonald, 2008). The Spearman’s rho allowed me to identify which components of lesson design were correlated. I interpreted the Spearman’s rho using Cohen’s three-way classification (small, medium, and large) of effect size. Cohen labeled the effect size as (a) small if the correlation or rho is equal to 0.10, (b) medium if rho is equal to 0.30, and (c) large if rho is equal to 0.50. However, it is worth noting that Cohen’s classification is based on the typical effect sizes that he encountered in the behavioral sciences. He cautioned against using his labels to interpret relationship magnitudes in other disciplines such as the social sciences and education because they likely have smaller effect sizes (Valentine & Cooper, 2003).

I started my statistical analysis by selecting categories that I believed might have relationships. First, I looked at whether the PTs’ development of student-centered lessons (Fig. 11) was correlated to the growth in their modeling practice (Fig. 8). I hypothesized that the PTs’ conceptualizations of more student-centered instruction would contribute to improvement of the modeling practice. In fact, I noticed that as PTs’ increased consideration of students in their lessons (teachers’ eliciting students’ prior knowledge, learners developing and engaging in investigations), they also increased engagement of their students in the modeling practice (naïve and revised modeling). Second, I analyzed whether the improvements in the PTs’ conceptualization of lesson goals that reflect big ideas in science (Fig. 1) was correlated with: (a) more productive driving questions (Fig.
5) and (b) objectives that are more aligned with standards (Fig. 3) in the lessons. These were based on my assumptions that as PTs gained a better understanding of the big ideas in their lessons, they would be able to provide better questions and identify appropriate standards based on the lesson goals of their lessons.

Finally, I looked at whether the PTs’ improvements in scientific practices (Fig. 7) might be correlated with their use of evidence in lessons (Fig. 10) and their identification of leverages (Fig. 14) in lessons. I suspected that as PTs progressed in their knowledge of scientific practice, they would be able to think of other ways to engage students in an investigation, such as using evidence as part of their lesson. Furthermore, I hypothesized that as PTs developed in their thinking about how to incorporate modeling and argumentation as parts of the scientific practice, they would be better able to use students’ prior conceptions as leverages in designing their lessons.

However, it is worth noting at this point that there are two reasons why I was not able to perform the statistical analyses of other categories that are potentially correlated (e.g. student-centeredness of lessons vs. leverages). First, I could not correlate categories from the interviews to categories in the lesson sets because they came from different points in time and thus did not provide me with the matched pairs that are required for comparison. For instance, the student-centeredness of lessons category (Fig. 11) was based on the clinical interviews from Methods I through Methods IV while the PTs’ knowledge of students’ alternative conceptions category (Fig. 13) was from Methods II through Methods IV. Second, my analysis was constrained by the different number of levels in each category and again did not provide me with matched pairs. There were categories that had three levels (e.g. Fig. 10—use of evidence in lesson design) and some
had two levels (e.g. Fig. 5—productivity of the driving questions), while other categories did not have levels (e.g. Fig. 2—performance-based objectives; Fig. 9—modeling). I provide the statistical results of these tests in the “Findings” section.

3.5 Trustworthiness

It is the prime concern of a researcher in a qualitative study to have trustworthiness. To establish trustworthiness, Merriam (1998) suggested ways to achieve internal validity and external validity in proposed studies. Internal validity is concerned with how the research findings are matched with reality and not only based on the researcher’s perspectives. To achieve internal validity, I triangulated my data and performed peer examination of the case. I used multiple data sources (philosophy papers, clinical interviews, lesson sets, and final reflection papers) to confirm the emerging findings and to construct plausible explanations about the phenomena being studied. For instance, I used clinical interviews and lesson sets to describe the ways in which the 15 PTs’ lesson designs changed over the four methods courses. Moreover, these different data sources provided perspectives (in categories and themes) of their knowledge of the learners.

Another way of enhancing internal validity was through peer examination. I shared my coding procedures, coding schemes, and categories to my fellow graduate students and my dissertation adviser and asked them to comment on them as they emerged (Merriam, 1998). According to Lincoln and Guba (1985), the peer reviewer acted like a devil’s advocate by asking the researcher hard questions about methods, findings, and interpretations. For instance, I shared coding procedures and lists of
categories that emerged from the first and second pass of coding clinical interviews. After reading several interview transcripts as a group, we saw that a previously identified category of instructional moves was not capturing the PTs’ descriptions of their roles as well as their students’ roles in the lesson. As a result, we came up with the student-centeredness of lessons category, which captured the different degrees of PTs’ consideration of their students (teacher-centered versus student-centered) during instruction.

Finally, external validity is concerned with the extent in which this research can be applied to another situation. To help the reader ascertain the degree and ways in which findings might be transferable, I included a detailed description of the site, participants, data collection, and analysis procedures to allow the readers to decipher for themselves if there might be a match with their own setting.
Chapter 4: Findings

4.1 Overview

My research questions focus on the ways in which PTs’ knowledge of MBI develops over the four methods courses, as well as PTs’ ability to use this knowledge in designing inquiry lessons. My research findings suggest that most PTs were able to increase their understanding of MBI, implement modeling in lessons, and account for students’ prior conceptions and difficulties while designing lessons. This chapter describes (a) PTs’ initial ideas of lesson design, (b) changes in the structure and components of lessons as a result of the methods courses, (c) PTs’ conceptions and implementation of MBI in instruction, (d) PTs’ challenges in designing lessons, and (e) PTs’ anticipation of students’ prior knowledge and alternative conceptions. The following sections elaborate on these results and characterize the PTs’ abilities and challenges in designing MBI lessons.

4.2 PTs’ Initial Ideas about Lesson Design

I began addressing my research questions by examining the PTs’ educational philosophy papers. These papers represent the PTs’ initial ideas about the components of an ideal lesson in biology, which I used as a proxy for their ideas of the best ways to teach and learn science. While the assignment did not directly ask for their ideas of MBI as it applies to designing lessons, the educational philosophy papers provided insights into what PTs’ thought of as the ideal structure and components of science instruction. Table 15 illustrates the salient themes that emerged from my analyses.
<table>
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<th>Category</th>
<th>Examples and key words for coding</th>
<th>Number of References (N=15)</th>
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| Group learning          | “Within their groups they reviewed what they had learned yesterday individually, and then they were each assigned a different part of the photosynthetic process, which they were to teach to each other.” – Molly  
**Key words:** groups, teaching each other                                                                                                                   | 4                           |
| Class discussion        | “After the experiments, the teacher has a guided discussion with the students to discuss experimental findings.” – Catherine  
**Key words:** question and answer, presentation, discussion                                                                                                    | 8                           |
| Lecture presentation    | “First I would begin by talking to my students about how living things grow. I would explain to them that every living thing is composed of cells and these cells grow and divide for repairs and growth.” – Nora  
**Key words:** I will show/discuss, lecture, instruct                                                                                                                                                     | 13                          |
| Hands-on                | “We will travel outside and while outside each student will be assigned something to find which they can talk about with the class that represents a part of photosynthesis.” – Molly  
**Key words:** lab, field trip, hands-on                                                                                                                                               | 10                          |
| Real-life connections   | “The content of the lesson itself should contain numerous real life examples and facts that would intrigue students, but be focused on a particular topic.” – Jake  
**Key words:** real world, motivate, intrigue, application                                                                                                                                         | 8                           |
| Multiple methods        | “Throughout teaching the section the teacher should provide a variety of different learning materials. Overheads, worksheets during and after class, at home reading, demonstrations and an occasional quiz should encompass all of the different types of learners that are within your classroom.” – Nina  
**Key words:** use of different materials, different methods of teaching, learning styles                                                                                           | 6                           |
| Use of models           | “Here, we could review the structure of a cell with a model. Looking at the model, the class can locate the nucleus and the chromosomes.” – Nora  
**Key words:** models                                                                                                                                                                               | 2                           |
With regard to the components of an ideal lesson in biology, the majority of PTs argued for experiential learning through hands-on experiences and experimentation. They argued for the importance of real-life connections to motivate students to learn. A majority of PTs also mentioned lecture-presentation and demonstration as part of the instruction. Moreover, several PTs discussed various methods of instruction and allowing students to work independently. These ideas, which reflected a blend of teacher lectures and students’ hands-on experiences, seemed to hint, implicitly, at a general view of instruction that involves students, but is heavily directed by teachers. The proposed investigations, discussions, and independent study were used merely to confirm what teachers introduced during lecture presentation or demonstration.

In addition, it is worth noting that the components of lessons that PTs identified at this stage did not reflect MBI instruction in any way. In fact only two PTs mentioned the use of models and modeling as part of the lesson. Participant Nora suggested using the model of a cell to review its parts and structure: “Here, we could review the structure of a cell with a model. Looking at the model, the class can locate the nucleus and the chromosomes.” However, Nora is using the model to convey information and not as a generative tool to develop students’ own ideas. While Jackie, another participant, mentioned incorporating student-generated models in her lesson, she suggested comparing these with other models or theories in order to provide different perspectives, which somewhat reflected what scientists do as they use alternative models to compare their own:

After preconceptions were cleared up, the teacher can use inquiry to try to help the student form the concept somewhat by themselves. Then the teacher might want to show the students models and the different theories of the concept to give
the students a unique way of looking at the information. (Jackie, Educational Philosophy Paper, Methods I)

Nevertheless, Jackie’s use of models in her instruction fell short of how scientists use models—to formulate hypotheses from models as well as to test and revise them.

In summary, the PTs’ initial ideas of science instruction invoked hands-on experiences but were heavily directed by teachers, which did not reflect an understanding or valuing of MBI instruction. In the next sections, I discuss the changes in the structure and form of lesson designs over time as a result of participating in the methods courses.

4.3 Changes in PTs’ Ability to Design Lessons

PTs designed lessons and units as part of their assignments in Methods II, III, and IV. PTs used a lesson plan template with specific structure and components to develop their assignments, which I described in chapter 3. My analyses of the different components of the lessons gave me insights into PTs’ successes and struggles, as well as the changes in how they conceptualized lesson plans.

4.3.1 Goals and objectives.

I started my analysis by looking at the goals and objectives because these guide the instructional methods of the lessons. Identifying appropriate and suitable goals for lessons is important because it helps teachers conceptualize the lesson through backwards design. This conceptualization includes identification of the “big ideas” in science, considerations of students’ prior knowledge and skills, and ascertaining target learning pathways for students in the lesson. The big ideas in science pertain to the understanding of the relationship between science phenomena (e.g. evolution) and causal explanation. I
also looked at other aspects of the instructional goals, that is, whether or not they were measurable, performance-based, and aligned with standards.

My analysis revealed that initially, the objectives provided by PTs in Methods II indicated a study of a science phenomenon (e.g. evolution) but lacked attention to the causal mechanism and evidence, which are part of the big ideas of science. For example, Jack’s lesson objectives contained big ideas (adhesion and cohesion) but lacked explanation of how adhesion and cohesion work to explain how water travels inside a plant: “The students will be able to demonstrate their understanding of adhesion and cohesion through classroom discussion. They will be able to generate models and revise them” (Jack, Lesson Set 1, Methods III). Jack mentioned in his reflection paper in Methods II that identifying and understanding the lesson’s big ideas was not that easy. He questioned his own understanding of the science concepts as well as reflecting on how he learned these concepts in school. Based on his experiences as a student in high school, science instruction seemed to focus on memorizing vocabulary words and did not emphasize a deeper understanding of the concepts:

Besides using data, I also didn’t quite have a handle on the idea of “big ideas.” When putting together the unit, at first there were a lot of learning objectives that our group had that we really thought the students should know, this was mostly because we had to learn them all in high school ourselves. That was probably the biggest hump to get over, leaving out the details, such as the names of all the stages in mitosis, that I remember studying so hard to memorize in high school. It took a lot of work to realize that in reality those defining terms weren’t actually part of the deeper understanding that inquiry teaching is after. Truthfully when I get a job and teach mitosis to a class there is a solid chance that they will be learning those terms but now I realize that they are only secondary to a deeper understanding of what is going on in cell division. (Jack, Final Reflection Paper, Methods II)
After the lesson design and teaching experiences in Methods III and Methods IV, PTs improved their ability to incorporate causal mechanisms with science phenomena as part of the big ideas in their lesson goals. As an example, Christine’s goals contained a big idea (diffusion) and an explanation of how it works (transport, factors that affect diffusion), which are associated with this phenomenon:

Students will be able to explain diffusion and the rules associated with this phenomenon. Students will be able to predict how diffusion is affected by temperature and describe compounds that undergo diffusion across the cell membrane. (Christine, Revised Lesson, Methods IV)

Figure 1 illustrates the changes in lesson objectives developed by PTs in Methods II through Methods IV.

![Lesson goals reflect big ideas in science](image)

**Figure 1. Lesson objectives reflect big ideas in science**

In addition to this reflection of big ideas, lesson objectives must be measurable and performance-oriented in a way that permits viable methods for teachers to evaluate students’ learning and progress in the lesson. Clearly identified student performance tasks in the lesson goals can also provide opportunities for teachers to adjust or modify their instruction based on students’ responses or enactments in the lesson. My analysis of
lesson goals and objectives showed that more than half of the goals in the lessons
designed in Teaching Experiment I assignment in Methods II were neither performance-
oriented nor measurable. Problems included: (a) objectives written in a form of questions
(“Why is photosynthesis important with respect to food chains?”—Sean), (b) objectives
as bulleted items or statements (“Dihybrid Crosses are used to test dominance
relationships among individuals who differ in two traits”—Patrick), (c) objectives as
tasks that the teacher would perform and not what students would be able to do in the
lesson (“Students will be led in scientific argumentation on why they think are right”—
Bani), and (d) objectives using words like “will know” or “will learn” that are not
measurable (“Students will learn the common characteristics of all vertebrates”—
Catherine). These types of objectives are problematic because they will not provide
information about what students have actually learned or will be able to do as a result of
the instructional engagement.

Again, after Methods III and IV, PTs were able to provide objectives that were
more performance-based. However, the majority of lessons contained performance-based
objectives that focused on factual knowledge and recall (“Students will be able to
describe the structure of a mitochondrion”—Anna, Lesson Set II, Methods III) rather than
higher level objectives that focused on application, analysis, and synthesis (“Students will
be able to predict how atoms will react chemically based on their atomic structure”—
Patrick, Lesson Set I, Methods III). Figure 2 illustrates the changes in lesson objectives
developed by PTs in the methods courses.
Another important aspect of lesson design is aligning the objectives to standards. This allows teachers to connect their lesson goals to the big ideas and curriculum objectives identified in the national or local standards. The process of aligning the objectives to standards can also provide opportunities for teachers to think about their students’ progress towards learning the knowledge and skills identified by larger governing bodies in education. Findings from my study suggest that as PTs focused on designing goals that were performance-based and focused on big ideas in science, they seemed to neglect aligning the lesson objectives to the national or local science standards. Initially, the majority of lessons developed in Methods II were adequately aligned with standards, which indicated that PTs were able to identify and use appropriate science standards even from the early stages of lesson planning and design. However, most lessons in Methods III had no standards, were missing some standards (e.g. scientific practices), or referenced irrelevant standards. This was also the case for lessons
developed in Methods IV, despite a clear section in the lesson template devoted to listing standards.

One possible explanation of this trend is that PTs unlearned or forgot what they know about aligning to standards. But the other and more probable reason was that there was a shift in PTs’ focus—from aligning to standards to developing the other components of the lesson that were more challenging for them, at the expense of explicitly addressing the former. Specifically, given the focus on MBI in the methods courses, PTs seemed to shift their energy toward developing the other components of the lesson, including better “driving questions,” and addressing students’ alternative conceptions, which I discuss in the next sections. Figure 3 illustrates the changes in the goal alignment with standards developed by the PTs in the methods courses.

![Figure 3. Alignment with standards](image-url)
4.3.2 Driving questions.

In addition to conceptualizing better goals and objectives for the lesson, PTs learned to develop better driving questions that would elicit students’ prior conceptions at the start of each lesson. The majority of lessons in Teaching Experiment I (Methods II) and in Lesson Set I (Methods III) had questions that were either unproductive (level 0) or were semi-productive (level 1). These driving questions were unlikely to elicit relevant prior conceptions due to their wording (syntax or vocabulary familiarity) or would only have elicited irrelevant prior conceptions. For instance, Catherine’s lesson asked students to provide what they know about biomolecules before the lesson: “[Individual students] will draw/write their ideas of examples of biomolecules worksheet 1.1 (5min)” (Catherine, Lesson Set I, Methods III). This question or task may not be productive in eliciting pre-conceptions because students might not know what biomolecules are or might provide irrelevant ideas. In a second example, Jack’s driving question about viruses was too broad and would likely elicit both relevant and irrelevant students’ pre-conceptions (level 1): “Begin the lesson by asking students what they know about viruses. It’s a general question that most of the students should have some input into” (Jack, Teaching Experiment Lesson Plan 1, Methods II).

Given the PTs’ experiences teaching students during their internship seminar, the majority of Lesson Set II (Methods III) and Revised Lessons (Methods IV) contained driving questions that were productive (level 2) to elicit students’ prior conceptions. This showed that PTs were able to develop better questions after working with students in the classroom. Driving questions became more specific and appropriate, as well as more
productive in eliciting relevant student’s pre-conceptions. For example, Catherine’s guiding questions were specific and potentially familiar to students:

Are the bones alive when they are inside a living body? What evidence do you have that makes you say so? What are bones made of? Can bones grow? (Catherine, Lesson Set II, Methods III)

Catherine’s driving or guiding questions can help students narrow the focus of their discussions and initial model development. Figure 4 shows the shifts in the productivity of the driving questions in lessons sets.

4.3.3. Assessments.

As part of lesson design, PTs were instructed to explicitly mention the different kinds of assessments they were planning to do with their students. Only through thoughtful planning of assessments can teachers know if students learned the knowledge and skills identified in the instructional goals of the lesson. In particular, we taught our PTs to use student-produced models as a way to monitor the development of students’ conceptual understanding in the lesson. My analysis showed that the majority of
assessments in lessons developed as part of the *Teaching Experiments* (Methods II) assignment did not provide assessment information. For instance, as part of her assessment, Christine mentioned using student-generated models and worksheets. However, the target of the lesson models (what she expected her student models to be about) was unclear, worksheets were not provided, and there was no mention of how she would use this information in her instruction: “Assessment: Models, preliminary and post-worksheets” (Christine, Teaching Experiment Lesson Plan 1, Methods II). On the other hand, the majority of lessons in Methods III and Methods IV contained assessments that were relevant to the objectives and were comprehensive. In the example below, Sean describes the different kinds of assessments that he would be doing throughout the lesson including the initial models, data obtained from experiments, and revised models:

> Student assessments are ongoing throughout this lesson. Current understanding and misconceptions of students have regarding human evolution and phylogenetic trees will be assessed from the initial review lesson. Engage students while they work in groups at their lab benches to be sure they understand how to analyze evidence and also that they are being specific with their models. After the lesson, review the various models to see what students’ learned in the lesson. Use the results to adjust the lesson in the future. (Sean, Lesson Set II, Methods III)

In addition, Sean mentioned in his final reflection paper the need for multiple forms of assessments to monitor students’ progress throughout the lesson. He mentioned using assessments to gauge students’ understandings in the lessons and to adjust the instruction as necessary. Furthermore, he mentioned that the naïve and revised models from individual students or groups could be used as assessments:

> To that end, formative and summative assessments are both critical elements of a good lesson (in any subject). By monitoring the progress of students’ thinking throughout a lesson, a teacher is able to understand aspects of the lesson that may need to be addressed or even changed...Formative assessment throughout the lesson may be done during class discussions, by analyzing students’ naïve and revised models (either by collecting them or having them present them), or by
listening to conversations when students are working in groups. (Sean, Final Reflection Paper, Methods III)

Figure 5 shows the shifts in the levels of assessments in lesson sets developed by the PTs.

4.4 PTs’ Understanding and Implementation of Model-Based Inquiry Practices in Lessons

4.4.1 Science practices.

Central to MBI as a scientific practice is its emphasis on students’ active role in constructing and testing of scientific models. In particular, MBI teaching requires PTs to design instruction that fosters students’ capacity to engage in modeling, gather and evaluate scientific evidence, and participate in discourse or argumentation. My analysis of individual lesson plans as part of the clinical interviews as well as lesson plan sets revealed initial challenges for some PTs in incorporating MBI into their lessons. Several lessons designed in Methods II and Methods III were teacher-centered (level 0) or experiment-driven. For instance, Patrick’s lesson focused on lectures and discussions in which the teacher provided the knowledge and explanations to students. Even when he
mentioned eliciting students’ prior conceptions in the beginning, it was not clear how he would address them in his lesson:

Review of topics from monohybrid cross lesson. Teacher should have students publicly answer questions about terms and concepts such as genes, gametes, alleles, chromosomes, dominance, and recessive. Teacher should assess students’ answers to identify any weaknesses in responses. Discussion should end with a review of Mendel’s three laws. Use a dihybrid cross to explain the concept of independent assortment. (Patrick, Teaching Experiment Lesson Plan 1, Methods II)

In addition to the teacher-centered lessons, a few lessons developed in Methods II were experiment-driven (level 1), in which the core activity involved students performing some type of investigation. At this stage, students were engaged in “cook-book” or procedural activities that did not include eliciting students’ pre-conceptions. As an example, Sean’s lesson included an investigation in which students would compare elodea and onion cells. He prescribed a procedure for students to follow:

Demonstrate how to prepare the slides (including how to carefully peel a thin portion of onion skin). Pair students up, and instruct them each to obtain Handout D (‘Laboratory Report Sheet: Comparing Elodea and Onion Cells’) and bring one microscope per pair to their lab benches. They may then approach your lab bench, where you will give each pair an elodea sprig; onion peel, pipette, and two slides with cover slips…Instruct them to follow the procedures written on Handout D. After a few minutes (after is becomes evident that most students have viewed the elodea leaf under 400X magnification), guide the students to understand that the small circles they are viewing are the chloroplasts. (Sean, Teaching Experiment Lesson Plan 1, Methods II)

On a positive note, the majority of lessons in Methods II through Methods IV included modeling (level 2A). This suggested that PTs’ view of science practices shifted—from hands-on investigations to modeling—at an early stage of their certification program. I believe that this change can be attributed to the experiences that PTs had as learners in MBI in the methods courses. Sean described in his reflection paper that before
Methods I, his idea of instruction consisted of a blend of lecture and hands-on investigation:

Before I entered this course, my idea of a good hands-on lesson consisted of what I myself had experienced as a student. This entailed the teacher presenting material, followed by having students follow an experimental plan (documented on a handout), and concluding with the handing in of a lab report. I have never experienced a class where I was able to choose what aspect of a phenomenon I would like to test for (like the inquiry lesson with the egg, where students chose what type of liquid to immerse their eggs into). I was very accustomed to cookbook labs and was unsure of how I was going to entirely avoid them as a teacher. (Sean, Final Reflection Papers, Methods I)

We can observe that Sean’s view of science lessons and instruction changed after Methods I through his incorporation of modeling and students’ prior knowledge as part of his lessons. MBI, he said, promoted more student engagement (by allowing students to evaluate each other’s models) and less teacher-direction:

My current understanding of investigation and model-building enhances those characteristics of a good science lesson mentioned earlier. For example, before any experimentation begins, the preconceptions and initial ideas students have regarding the phenomenon to be investigated should be explored. The best way to do this is have students develop models of how they believe the complex processes work. Also, instead of the teacher simply telling them they are right or wrong, their classmates’ criticisms may be even more beneficial. (Sean, Final Reflection Paper, Methods I)

Similar to Sean, other PTs’ views of modeling as a scientific practice were reflected in the lessons that they developed in the methods courses. Lessons included activating and eliciting students’ prior knowledge as well as creating and discussing models. For example, Catherine used pictures to prompt students’ pre-conceptions about characteristics of invertebrates and vertebrates. She also encouraged them to share and discuss the individual models:
Class should begin with a PowerPoint presentation of pictures illustrating both invertebrates and vertebrates. As you go through the slides, you ask the students if the organism is an invertebrate or vertebrate and their reasoning why. (5-10 min) After the slide show is over, put the class into groups of 4-5 students each. Ask them to discuss what characteristics define a vertebrate. Give each group a piece of large poster paper. Tell them they can illustrate or write an explanation of what defines a vertebrate. (15-20 min) When they are done, have the students post their models around the room. Have each group communicate and explain their vertebrate characteristic models. Engage the class in a discussion about the models by asking: “Are there similarities and differences in the different groups’ models?” And “Do you agree or disagree with Group 1’s model? Why or why not?” (Catherine, Teaching Experiment Lesson Plan 1, Methods II)

On the other hand, PTs failed to include argumentation (level 2B) as part of science practices. Argumentation challenges students to use evidence from their investigations to support or refute and revise their initial models. In most cases, however, PTs ended their lessons by asking students to revise their models and present them in front of their classmates without any follow-up argument or discussion around models and evidence. For instance, Jack wrote “After the mini-lab, have students revise and explain their models of how trees take up water. Have students present their model to class and eventually form a class model that best depicts the phenomenon” (Jack, Revised Lesson, Methods IV).

One of the possible reasons for the absence of argumentation in lessons may be that PTs were not sure about the difference between discussion and argumentation. According to Catherine, she realized that good argumentation required back-up evidence after she participated in an inquiry unit about cancer, reading assignments, and lesson development in Methods I and Methods II:

I never really understood what the difference was between discussion and scientific argumentation. I finally got it this semester though. I think it was a combination of the lessons we did as a class on cancer last year, readings, and having to develop the units. I learned that scientific argumentation means
statements have to be backed up by evidence, whereas in a discussion or a debate, statements can be backed up by opinions and evidence, but evidence is not necessary. (Catherine, Final Reflection Paper, Methods II)

Another possible reason might be the lack of time and availability of suitable data that PTs could use in the classroom. For instance, Sean mentioned the difference between scientists conducting inquiry versus classroom inquiry:

Many of the ways in which students connected the species together may be different. Explain to students that scientists are working with much more evidence (and many more species) than they have just worked with and this is the reason why many scientists do not agree with each other on how these species fit together phylogenetically. (Sean, Lesson Set II, Methods III)

Figure 6 shows the shifts in the science practices in lesson sets developed by the PTs.

![Figure 6. Science practices in lesson sets](image)

**4.4.2 Modeling (Part I)**

My analysis of lesson designs through clinical interviews told a similar story regarding PTs’ implementation of modeling in lessons. In Methods I, several lessons did not incorporate the modeling process (level 0). These lessons focused on hands-on
investigations without eliciting students’ prior knowledge. By the end of Methods I and Methods II, PTs had begun to include the language of modeling in their lessons; however, the modeling process was prescriptive and procedure-oriented (level 1). At this level, PTs mentioned the steps of modeling (e.g. gathering naïve models, testing and revising models) but failed to explicitly mention the scientific models that the students were working on. For instance, Patrick said that in the process of MBI, students engage in developing initial models, conducting research and experiments, revising models, and sharing of ideas with other students:

With the initial model, maybe students would be a little to set to stick with their initial model. They should probably after research, after experiment be ready to develop a new model ... All the while this research and experimentation should be in a group. It doesn’t have to be a big group. Just so that students don’t wonder off. They are sticking in a group talking to people. They are sharing ideas. And that’s it. (Patrick, Clinical Interviews, Methods I)

In this example, Patrick fails to explicitly link the process of modeling to the science concepts that students are working on. His modeling process is generic and prescriptive in that it could be used in any lesson or topic. On the other hand, lessons from interview transcripts in Methods III contained a more sophisticated modeling practice (level 2A) in which target models were explicitly described and connected to the overall modeling practice. In Sean’s lesson below, he mentions that after modeling and argumentation, the models should contain and explain the process of photosynthesis:

After the group model is done, I would have them each group present to the class, post them around the room, and then we would engage in classroom argumentation to see what the differences were and to see if we could reach a class consensus. The models should contain all three of these aspects: how plants get and convert energy—that would be if they put the nutrients chlorophyll and light; equations—inputs and outputs and using glucose as a source of energy. I would require them to somehow explain the end results. If they explain what the end results are and why they have chosen these results that answer should
include— well I included glucose because that is a source of energy. (Sean, Clinical Interviews, Methods III)

In addition, Sean’s views of models consisted of characteristics and explanations (how plants get and convert energy), which reflected a good understanding of models.

However, similar to the lesson sets, only a handful of PTs mentioned argumentation (level 2B) as part of MBI lessons in clinical interviews. These PTs indicated the use of evidence from experiments to revise and argue for or against a model. For example, Nora’s plan was for her students to examine data and use that information to justify their models:

> From that they can analyze that data and make some charts to see the correlation between the different variables in the experiment. After that, I will have them share the results to the class. Every group would share and have the class argue using evidence from their experiments. And have them justify what their argument is about. After argumentation, I will ask them to revise their models. (Nora, Clinical Interview, Methods III)

Unfortunately, the majority of lessons did not include argumentation. They did not use evidence to inform their discourse around models. In this case, lessons ended with a revision of models or a lecture. For instance, Catherine mentioned that after investigation, students will revise their models using data from their experiments. Then she mentioned conducting a lecture to summarize the lesson:

> And then I was saying, after that [investigation], have the groups revise the model, then come back and revise the model as a class, using the data. And then, have a benchmark lecture on cellular respiration. (Catherine, Clinical Interview, Methods III)

In addition to lack of argumentation in lessons, there was a decrease in the number of lessons with level 2 modeling (sophisticated modeling practice) and an increase in level 1 modeling (script modeling) in Methods IV. It is not clear why, but this might have been be due to the lower motivation of PTs to complete the interview since
this task was their final assignment in the program. Figure 7 shows changes in modeling as part of lessons in clinical interviews.

![Figure 7. MBI in lessons from clinical interviews](image)

**4.4.3 Modeling (Part II)**

Further analysis of modeling in lessons focused on accounting for the different stages of modeling in the PTs’ instruction. In my analysis, I counted lessons that had naïve modeling only, naïve and revised modeling, and data provided to students. My analysis of lesson sets revealed that the majority of lessons in Teaching Experiment I (Methods II) and Lesson Set I (Methods III) contained naïve modeling only. At this stage, lessons included uncovering students’ prior knowledge and an investigation, but did not contain revision of models. One of the possible reasons was that lessons designed by PTs were geared for 40–60-minute class period, which was just enough time to have students create initial models with no time to test or revise them. Another possible reason was that PTs struggled with models and modeling themselves. According to Molly, she had
difficulty in creating MBI lessons because she was unsure of what models were herself. She was not sure of how to incorporate a model within a lesson:

I still to this day struggle with making a model. When we first began the lead unit, I sat contemplating how to make a model, even though at that point during class we had already made so many models. I think that the only thing which can possibly help me with this difficulty is practice. The more I develop my modeling skills the better I can demonstrate these skills to my students. This struggle also ties into my struggle into how, within every lesson, I will be able to incorporate a model. (Molly, Final Reflection Paper, Methods I)

On the other hand, as PTs gained experiences in MBI and incorporating models in lesson designs, their view of models and MBI lessons improved. Nina reflected on how her view of models changed over Methods II. She described how her idea transformed from a representational model into a dynamic model. According to Nina, models are not only representations but they can also be used to generate questions as well as test, predict, and explain phenomena:

A big part in what changed my idea of how we should be teaching science has to do with how I now view models. I always believed that models are simply representations of ‘things’ that cannot be seen by the naked eye…Models were mainly used to illustrate structure. It wasn’t until this class that I learned what models can really be used for. Models are representations of ideas. They can be temporary descriptions and explanations of the world… Models are meant to generate questions and ideas. They can explain and predict phenomenon. Models are tools for developing and testing our ideas about structures and processes. (Nina, Final Reflection Paper, Methods II)

In addition, given the focus in the methods courses on using evidence as part of inquiry, PTs began to provide evidence for their students as a teaching strategy in the Lesson Set II (Methods III) and Revised Lesson (Methods IV) assignments. PTs provided evidence to students as part of their investigations whenever experiments were not feasible due to lack of time and resources in the classroom. In addition, the majority of lessons after Methods III included a variety of scientific practices, such as naïve and
revised modeling, evidence provided to students, and guided investigations. In the next section, I provide examples of evidence and discuss challenges encountered by PTs in identifying appropriate evidence as part of investigations in their lessons. Figure 8 shows changes in modeling as part of lessons sets.

![Figure 8. Modeling processes in lesson sets](image)

### 4.4.4 Use of evidence in MBI lessons.

The capability to find, adapt, or generate suitable evidence as part of student investigations was not easy for most PTs. Identification of good data to provide students with is important in MBI because their analyses, discourse, and revision of models depend on it. In my analysis I found that the majority of data provided by PTs was not suitable or was inadequate for students (level 1). For example, Bani’s evidence (Table 16) contains information that is dependent on the knowledge of chemistry (mole, compounds, and chemical transformations) in order to make sense of the data. This inquiry activity will most likely end up in a teacher lecture because students may not be able to decipher the evidence and its connection to the lesson.
Evidence Sheet 2. When scientists tested for the presence of fatty acids they found the following information.

<table>
<thead>
<tr>
<th>Acetyl CoA</th>
<th>Malonyl-CoA</th>
<th>CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 mol.</td>
<td>0 mol</td>
<td>0 mol.</td>
</tr>
<tr>
<td>2 mol.</td>
<td>1 mol</td>
<td>1 mol</td>
</tr>
<tr>
<td>4 mol.</td>
<td>2 mol</td>
<td>2 mol</td>
</tr>
<tr>
<td>6 mol.</td>
<td>6 mol</td>
<td>6 mol</td>
</tr>
</tbody>
</table>

Malonyl-CoA is a substrate formed from acetyl-CoA and carbon dioxide, and is required to form and make the chains of fatty acids longer. Palmitate is a 16-carbon fatty acid. When you add glycerol-3-phosphate it makes triacylglycerols (TAGs).

Table 16. Evidence provided by Bani in Lesson Set II (Methods III)

Another problem with evidence chosen by PTs was that it basically contained the answers. For instance, Patrick wanted his students to make a model of digestion but then essentially provided them with answers in the form of evidence. The only thing that they had to do was read:

How is food digested? Digestion involves mixing food with digestive juices, moving it through the digestive tract, and breaking down large molecules of food into smaller molecules. Digestion begins in the mouth, when you chew and swallow, and is completed in the small intestine. The large, hollow organs of the digestive tract contain a layer of muscle that enables their walls to move. The movement of organ walls can propel food and liquid through the system and also can mix the contents within each organ… (Patrick, Lesson Set II, Methods III)

Jessica, in her reflection paper, noted how she struggled and second guessed her choice of evidence. She wanted to make sure that her students would be able to interpret and connect the data to the lesson’s objectives:

Even after designing the cardiovascular unit, I still find myself struggling somewhat with evidence: how to determine what type of evidence to use, how to best present evidence, and finally, how to incorporate it into the unit. I often second guess myself at what evidence I am choosing to use and whether or not the students will be able to make the connections and inferences I hope they will make. (Jessica C, Final Reflection Paper, Methods IV)
In addition, Jack mentioned that crafting appropriate evidence depends on anticipating students’ naïve models. According to him, an inquiry lesson may involve data that can be used to tackle students’ alternative conceptions, which is an example of a good use of evidence:

I also feel that I have much more to learn about creating an inquiry lesson. I need to learn how to anticipate wrong models from my students; because once I have the right answer fixed in my mind I have trouble exploring any incorrect options. Also the work involved in collecting materials for the students to use based on my anticipation of their models and where I can give them the opportunity to disprove their own and others ideas specifically on data I have found to clarify that exact point seems daunting. (John, Final Reflection Papers, Methods II)

As PTs gained more experience in analyzing data as learners, and as they learned to evaluate evidence as part of lesson designs, several improved their ability to identify or adapt evidence that was adequate for meeting the learning objectives (level 2). As an example, Catherine provided the information below (see Table 17) for her students to discuss why humans, particularly those who are pregnant women and adults over the age 24, need calcium. Furthermore, she wanted them to explain what makes bones release or deposit calcium.

<table>
<thead>
<tr>
<th>Information 1</th>
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<tr>
<td>Requirements of calcium are greatest during childhood, adolescence, pregnancy, and breastfeeding. Recommended daily intake (of elemental calcium) varies accordingly: 400 mg for infants 0–6 months, 600 mg for infants 6–12 months, 800 mg for children 1–10 years, 1,200 mg for ages 11–24 years, and 800 mg for individuals over 24 years of age. Pregnant women require additional calcium (RDA 1,200 mg). Many experts believe that elderly persons should take as much as 1,500 mg to help prevent osteoporosis, a common condition in which bones become weak and fracture easily due to a loss of bone density.</td>
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<table>
<thead>
<tr>
<th>Information 2</th>
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<tbody>
<tr>
<td>Calcium is the mineral in your body that is stored by your bones and keeps them strong. Ninety-nine percent of the calcium in your body is stored in your bones and teeth. The remaining 1% is in your blood and soft tissues and is essential for life and health. Without this tiny 1% of calcium, your</td>
</tr>
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</table>
muscles wouldn’t contract correctly, your blood wouldn’t clot and your nerves wouldn’t carry messages. There are only two ways you can get this essential 1% of circulating calcium- from the calcium in your diet and from the calcium in your bone. It is mainly the calcium in your diet that spares, or protects, the calcium in your bones. In addition to their structural role, your bones are your emergency supply of calcium. Your body actually tears down and builds bone all of the time. If you don’t get enough calcium from the food you eat, your body automatically takes the calcium you need from your bones. If your body continues to tear down more bone than it replaces over a period of years, your bones can become weak and break easily. This leads to the crippling bone disease called osteoporosis.

Table 17. Evidence provided by Catherine in Lesson Set II (Methods III)

I considered Catherine’s data as level 2 because they were written in ways that students could comprehend and relate to, and required synthesis for students to answer the guide questions. According to Nadia, appropriate data is critical for students to make sense and engage in the experiment in order to learn the science concepts in the objectives of the lesson. Evidence should be applicable for the age and ability levels of students:

I have learned that provided [sic] data and/or experiment [sic] that will generate data are very critical. Everything could be spoiled if data to obtain evidence for model revision are not of clear and convincing in their nature. For example, if given data are too difficult for student’s level of knowledge/ability they get frustrated and give up. A good example that I had much success with was the experiment with eggs in different solutions to show osmosis (and explain why the whales died in fresh water). Much time should be spend on inspecting and analyzing data, so the students all understand the meaning of data and how they are used for evidence and for the scientific argument. (Nadia, Final Reflection Paper, Methods III)

Moreover, Nadia said good evidence can foster meaningful discussions and argumentation. Figure 9 shows the shifts in the levels of evidence provided by PTs in their lesson sets in Methods II through Methods IV.
4.5 Designing Student-Centered Lessons

Another major finding in my analysis of lessons was the growth in PTs’ considerations of their students while designing lessons. Designing student-centered lessons is at the core of the MBI framework. Within the student-centeredness of lessons category, PTs described their roles as well as their students’ roles in the lesson. PTs’ descriptions of the lesson sequence encompassed the different degrees of their consideration of students during instruction: from level 0—teacher-centered (lecture or demonstration) and level 1—partly student-centered (blend of lecture and student investigations), to level 2—student-centered (students’ modeling practices) lessons. Lessons that were student-centered tended to have: (a) a decrease in the number of teacher-centered lessons that did not include modeling, (b) an increase in student-centered approaches (e.g. eliciting students’ prior knowledge) to learning, and (c) an increase in PTs’ ability to anticipate what students knew or would be able to do.
Initially, the majority of lessons that the PTs designed in the first two courses were lecture-based and did not consider students’ prior conceptions (level 0). At this level, teachers provided information to students in a lecture or demonstration and then asked them to conduct an investigation to confirm what was taught during lecture. As an example, Ava came up with questions for a class discussion, an activity to look at labels in drinks, and a lecture:

I will have quick question for them: “Where do people get their energy from?” They can look at the ingredients in the labels of bottles of energy drinks and pick two or three ingredients and maybe look for where glucose is coming from. And from there you can let them know that there is a process where glucose and oxygen can give energy and possibly create a naïve model of the process of respiration. And after they are done with more investigation, they can go back and revise their models and present them to class. (Ava, Clinical Interviews, Methods II)

Even when Ava’s language included the terms “models,” it is noticeable that her lesson was teacher-centered in that the teacher provided the question and explanations to drive the science concepts, and that the lesson did not consider students’ models.

Moreover, when the interviewer asked her about what she planned to do in between the naïve and revised modeling activities, she answered “that will be a quick lecture [about] the actual respiration process because some of it can be technical.”

Lessons designed in Methods III and Methods IV, however, had components that were teacher-centered as well as components that included student’s hands-on learning experiences (level 1). For instance, Nora described her instruction with the following components: eliciting student ideas, modeling, student investigations, data analysis and presentation, and a lecture to end the lesson:

I will begin with a guiding question … how can a red wood tree grow so tall? Then I will ask them to create a naïve model to get their prior knowledge regarding the guiding question… I will then introduce an experiment of some sort
about photosynthesis, plants, light, CO₂, probes to get CO₂. I will ask them to do an experiment of some kind that will show the changing of concentrations of O₂ and CO₂ by keeping the probes there to see the changes and what is going on. From that they can analyze that data and make some charts to see the correlation between the different variables in the experiment. After that, I will have them share the results to the class... hopefully they are in the same page but if not I will end with a quick benchmark lecture to get everyone in the same page. (Nora, Clinical Interviews, Methods III)

While the lesson had components that were student-driven (naïve modeling, hands-on investigation, sharing results), the teacher provided the experiments and connections (through lecture) for his/her students.

On the other hand, half of the lessons developed in Methods III were student-centered lessons (level 2). At this stage, PTs’ lessons involved active participation of students: learners engaging in scientifically oriented questions, teachers eliciting students’ prior knowledge, learners developing or engaging in an investigation, learners gathering evidence and formulating explanation, and learners communicating and justifying explanations. Moreover, these lessons included making connections to scientific knowledge, modeling practices, and/or explicitly mentioned anticipated outcomes from students. For example, Molly described a lesson in which she would elicit and adjust her activity depending on her students’ prior knowledge:

So by starting with plants, you can get them thinking how they make their own food… and how do we get our energy? … I would like to see their prior knowledge …if there is no clear understanding and there is really no prior knowledge then I wouldn’t have them model… depending upon their prior knowledge…I know this sounds crazy but I would probably give them some experiments that scientists did to figure out how we get our energy…Like what they ate this for 20 minutes and they were fine or they ate this for 20 minutes and they didn’t feel well. So on and so forth. Then I would see if we added something to that prior knowledge… (Molly, Methods III)

Molly’s experiment or suggestions are meant to help her students think about the question. In addition, Molly described how she would demonstrate an experiment, ask
her students to design and conduct their own experiments, and end the lesson by revisiting the students’ initial models:

I was thinking maybe I would do some sort of small experiment in front of them some sort of to get them going …maybe I would run in place and take my pulse… And then have them design an experiment… I want them to do [their experiments] to see what happens… [And] once they are finish with their experiments, I want us to get together and share what they did… [next] some sort of small benchmark lesson, just very short, maybe on oxygen, glucose, carbon dioxide and water and how those four work together that may get them thinking… I would have them go back and [and revise] their naïve models… (Molly, Methods III)

Figure 10 shows the shifts in the student-centeredness of lessons from clinical interviews.

4.5.1 PTs’ conceptions about students’ knowledge.

PTs’ knowledge about what students already knew or were able to do seemed to improve in the methods courses. My analysis showed that the majority of lessons in Methods I and Methods II did not mention conceptions about students’ knowledge and skills, or had vague conceptions about this area. For example, Molly, in Methods I, said “I guess I would want to go over the process of respiration with them but I don’t know
the background and what was covered.” Molly was not sure about the extent to which students’ knew about the process of respiration. Similarly, Jackie in Methods II said that students most likely have heard of photosynthesis but did not provide any detail about its process: “Since this is a high school level most likely they have heard of photosynthesis and that is what is involved with this.” Jackie failed to mention what students know or do not know about photosynthesis.

On the other hand, there was an increase in PTs’ conceptions of students’ knowledge in Methods III and IV as evidenced by PTs’ (a) voicing students’ ideas, (b) describing students’ knowledge and skills, and (c) referring to learner’s history, which I describe in the following section. By “voicing-out” students’ ideas, I mean that the teachers would speculate as to what sorts of responses they might get from students, often acting out student talk. Christine’s lesson exemplified this case. She mentioned possible conceptions or ideas that her students may have had regarding where plants get their food:

I would start by asking how plants get their food if they don’t get it by eating things. The kids are going to be like, “Venus flytrap eats flies” but that is the exception to the rule. So, kind of get kids to think about how plants are stationary so how are they able to get food. See if anyone knows that plants make their own food, so ask them to explain a little more along those lines. But I am pretty sure that kids in high school don’t have a grasp on photosynthesis so umm after that, say let’s take a look at things that plants do have access to, like sunlight, air, nutrients, soil, water and then, from there, break down air because it is a mix of gases. Get them to kind of isolate carbon dioxide plants make oxygen. (Christine, Clinical Interviews, Methods III)

Christine seemed to know more about students’ knowledge compared to Molly because she actually voiced-out what students might say in response to her questions (“Venus flytrap eats flies”), and what knowledge they may have that she can build on. In Methods I, Christine mentioned that her students would be able to explain what plants need in
order to live: “They might come up with water, soil, air and kinda that stuff, and ask them individually to draw how these things create matter of the branch” (Clinical Interviews, Methods I). Christine explicitly identified the ideas that her students might have. Figure 11 shows how PTs’ conceptions of students’ knowledge in lessons developed during the clinical interviews.

![Figure 11. PTs’ conceptions about students' knowledge in lessons designed in clinical interviews](image)

In addition, PTs’ knowledge of students’ potential difficulties and alternative conceptions increased in the methods courses. Specifically, the majority of lessons in Lesson Set II (Methods III) identified what students did not know about the topic. In the example below, Jackie explicitly mentions how her teaching strategies and activities will address student difficulties and alternative conceptions:

Many students by 9th grade know there are organelles within a cell; however, students often do not understand these organelles carry out processes which help the cell survive. By introducing the characteristics and functions a cell needs to survive first, this lesson will reinforce that cell function and structure is directly linked to organelles. In addition, many students do not know what the inside of a cell or the plasma membrane looks like although they are aware organelles are components of a cell. Students are unaware the plasma membrane has components (lipid bilayer, carbohydrates, protein channels) which are important to the survival of the cell. This lesson will expand the students’ understanding by
allowing them to participate in online simulations. In combination with the interactive PowerPoint, the students will be revising their naïve models of organelle structure and function within a cell. (Jackie, Lesson Set I, Methods III)

Jackie’s teaching experiences in Methods III helped her reflect on the sequence of topics and what students are expected to know based on that sequence. Moreover, the PTs’ experiences working with students during the internship seminar as part of Methods III fostered an awareness of what topics were difficult for students. Based on Nina’s teaching experiences during her internship, she realized that her students were still confused about the differences between animal and plant cells, even after a lecture and investigations. She explicitly described what her students struggled with in the lesson:

Sure, they may be able to take down the information you give them but they do not really understand them, let alone are able to conceptualize the topic. For instance, my students were so confused in the cells unit. They looked at plant cells and animal cells under the microscope. They even got the animal cells from themselves! But in the end they were still unable to fully understand that we are made up of cells and that animal and plants cells have a few very different characteristics that are extremely important to how we survive and function. (Nina, Final Reflection Paper, Methods III)

Figure 12 below shows the changes in PTs’ knowledge of students’ potential difficulties and alternative conceptions in lesson sets developed in Methods II through Methods IV.
Figure 12. PTs’ knowledge of students’ difficulties and alternative conceptions in lesson sets

4.5.2 Leverages in students’ prior knowledge.

PTs used their knowledge of students’ prior conceptions as *leverages* to build new learning experiences. My analysis of lesson sets from Methods II through Methods IV revealed that the majority of lessons designed as part of Lesson Set I (Methods III) and Revised Lessons (Methods IV) did not mention students’ prior learning history (level 0). As an example, Christine described what her students are going to do and not what was learned before this lesson about diffusion:

> In this lesson, students will encounter demonstration that center around the concept of diffusion. They will experience diffusion then define their experience in their own words. They will make educated predictions of the movement of particles across a membrane based on their experiences. (Christine, Revised Lesson, Methods IV)

At the same time, several PTs mentioned students’ prior learning history that was brief or insufficient throughout the methods courses (level 1). For instance, Nora’s descriptions of what her students potentially know about tissues were vague and insufficient (knowledge of the different shapes of cells):

> Students may have prior ideas of what these tissues are since students were required to take biology as a prerequisite to Human Anatomy and Physiology. Students may know the different shapes of the cells but may be unable to identify the name and location where they can be found. Students should have a grasp on the microscope, its parts, its functions and how to correctly use one for lab. (Nora, Lesson Set I, Methods III)

Instead of elaborating on what her students knew or did not know about cells, Nora mentioned another concept or skill (parts and function of a microscope) that they might be familiar with. On the other hand, the majority of lessons designed by PTs as part of Teaching Experiment I (Methods II) and Lesson Set II (Methods III) identified students’ prior learning history (level 2). This awareness included consideration of the sequence of
topics in a unit (or over a semester) and references to prerequisite knowledge that
students must have prior to the lesson. In the following example, Ava mentions the
concepts that students learned in the previous lessons (continental plates) and how she
would use these concepts in the new lesson about the ocean floor at shallower depths:

Students have been learning the topography of the sea floor and plate tectonics. They know where the plates are located, how the sea floor spreads at the Mid-Atlantic Ridge while oceanic plates are pushed under continental plates due to differing density of the plates. Activities previously done by mapping where earthquakes occur and extrapolating to how this information applies to plate movement, and the reconstruction of Pangaea has helped students understand how the continents have broken up and move…These can be used to build upon and help relate what is going on the sea floor to what they have learned about the ocean at shallower depths. (Ava, Teaching Experiment I, Methods II)

Figure 13 illustrates the changes in PTs’ knowledge of students’ prior learning history
that were used as leverages in lessons developed in Methods II through Methods IV.

![Leverages](image)

Figure 13. PTs’ identification of students’ prior learning history (leverages) in lesson sets
4.6 Results of the Statistical Analysis

4.6.1 Designing student-centered lessons promotes modeling.

As I described in the statistical analysis of my methods section, I calculated the Spearman’s rho (two-tailed at confidence level of 95%) in order to determine the correlation and significance of various numerical scores that I obtained from my coding of clinical interviews and lesson sets. Then I used Cohen’s three-way classification (small—0.10, medium—0.30, and large—0.50) to interpret the effect size of the Spearman’s rho. It is worth noting that, after conducting several analyses that I mentioned in Chapter 3 (e.g. student centeredness of lessons vs. modeling, lesson goals reflect big ideas vs. productivity of driving questions, science practices vs. use of evidence in lessons), I only found one possible correlation: student-centeredness of lessons (Fig. 11) and modeling (Fig. 8). The Spearman’s rho correlation was 0.5573 (p=0.0309) in Methods I, 0.5382 (p=0.0387) in Methods II, 0.4855 (p=0.0668) in Methods III, and 0.5190 (p=0.0474) in Methods IV. Using Cohen’s classification, the rho of about 0.50 suggests a large effect size—designing student-centered lessons has a strong and positive relationship to modeling. The difference between student-centered lessons and modeling was statistically significant at p<0.05 (2-tail) in Methods I, II, and IV.

Table 18. Results of the Statistical Analysis

<table>
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<th></th>
<th>Spearman’s rho</th>
<th>p-value</th>
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<tbody>
<tr>
<td>Methods I</td>
<td>0.5573</td>
<td>0.0309</td>
</tr>
<tr>
<td>Methods II</td>
<td>0.5382</td>
<td>0.0387</td>
</tr>
<tr>
<td>Methods III</td>
<td>0.4855</td>
<td>0.0668</td>
</tr>
<tr>
<td>Methods IV</td>
<td>0.5190</td>
<td>0.0474</td>
</tr>
</tbody>
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This suggests that designing lessons that are student-centered can potentially contribute to PTs’ incorporation of modeling in lessons. For instance, Nadia started her lesson by describing what she thought her students learned before, what they knew or did not know, and what potentially could excite them to learn the new concepts:

Of course how I start it depends on what they learned before that… They understand that and in carbohydrates, not only do they get how the molecule is being synthesized but they also get why for the energy and this energy is stored in molecular bonds. So they have this previous knowledge already and … they know plants do photosynthesis and build sugars and they mostly know that at least in high school that is the case. So it is not hard to ask the connection. Make them excited with various types of carbohydrates and they usually don’t know cellulose and they are marveled by how the whole trees are being built out of glucose … (Nadia, Clinical Interviews, Methods III)

Then, Nadia provided questions to engage them in a discussion and elicit their preconceptions:

Then I asked them “isn’t that wonderful, how to plants do that, how do they build molecules out of nothing?” … It is a very basic straight forward question but I think they are curious enough at this point so it creates a need to know. Discuss it in class because they come up with a lot of ideas… And the key thing of course this conversion of energy because it is a hard concept but again because they know that energy is being stored in chemical bonds this could be used for discussion…So that is all the discussion and we could make a naïve model… (Nadia, Clinical Interviews, Methods III)

After eliciting students’ naïve models, Nadia mentioned asking students to conduct investigations in groups using an online simulation. According to her lessons, students would then be expected to conduct their investigations, report their findings, revise their initial models, and create a class consensus model:

I would split them in groups and work with data. First ask questions, make a solid naïve model of the group and then work on it by giving them more like a simulated computer, something about photosynthesis where you can actually have that at the same time and have something on respiration where you can actually generate data yourself. You manipulate the environment. Let’s say you can manipulate the amount of light, you can manipulate the presence or absence of chlorophyll. The basic elements which make it happen you can vary… [After that,
students] can revise their models. Then discuss it in class and make a class model... (Nadia, Clinical Interviews, Methods III)

This example showed that Nadia’s consideration of her students’ prior knowledge and interests as she planned her lesson provided a platform to engage her students in modeling.

However, there was no statistical difference in the correlation in Methods III. I am uncertain as to why this might have been. In Methods III, the PTs gained experiences in the classrooms with students during their internship seminar. The lack of correlation may be due to the PTs' learning curve in this course as they negotiated what they learned from the previous methods courses and at the same time questioned the feasibility of implementing MBI in the classroom. For example, Christine claimed to believe in the inquiry approach to teaching science but questioned her ability to engage students in this teaching approach particularly those students who are not accustomed to this type of learning:

I am still unsure as to where and how I can use inquiry in my teaching and still meet standards. I understand that in perfect test schools with students who have been cultured to investigate inquiry material and stuff that this method is proven highly effective and time efficient, however to bring it to a school where the students are not assimilated to this material is such a challenging and daunting task. I know this from personal experience now. I do feel that I can incorporate it into my teaching style slowly over time so I increase my comfort level and so I can respond to the needs of the students, and I am willing to make these adjustments because I believe that inquiry is effective… (Christine, Final Reflection Paper, Methods III)

Christine also felt that learning how to teach science through inquiry and respond to the needs of her students take time.
4.7 Summary of Findings

The findings from my analyses provided evidence to support positive changes in PTs’ knowledge of MBI and its implementation in lesson designs. In particular, PTs were able to design lessons with: (a) objectives that incorporated big ideas in science (science phenomena and causal explanations), (b) performance-oriented goals, (c) driving questions to elicit relevant students’ pre-conceptions and (d) multiple forms of assessment that monitored students’ progress during the lessons. Moreover, I found several shifts in PTs’ knowledge of MBI and its enactment in lessons: (a) from teacher-centered and experiment-based to lessons with modeling, and (b) from script modeling to sophisticated modeling practice in which the target models were explicitly described and connected to the overall modeling practice. These findings pointed to growth in the sophistication of PTs’ understandings of models and modeling in lessons that they developed in the methods courses.

There was also a growth in PTs’ considerations of students’ knowledge and skill in lesson design. These considerations included PTs’ voicing out of students’ ideas, identifying learners’ history, and detecting students’ potential difficulties with the lessons. PTs used their knowledge of students to leverage new learning and to craft lesson sequences that better met students’ needs. On the other hand, PTs struggled to provide suitable evidence for their students to use as part of investigations and failed to incorporate argumentation in MBI. Specifically, it was challenging for PTs to come up with evidence because its composition depends on anticipation of students’ prior knowledge, including alternative conceptions. With regard to argumentation, PTs did not mention the use of evidence to revise and argue for models.
Chapter 5 begins with a discussion of the implications for pre-service science teacher education, followed by suggestions about future research that is warranted from this research project.
Chapter 5: Discussion, Implications, and Limitations of Study

Science education reforms in the 1980s and 1990s have asked teachers of science to plan and implement inquiry-based instruction and to facilitate student learning in a more conducive learning environment (AAAS, 1993; NRC, 1996). Moreover, recent calls to refocus science education have emphasized the development of scientific knowledge through model-building and argumentation (Duschl et al., 2007; NRC, 2011). MBI instruction involves an understanding of scientific knowledge as ever-evolving conceptual models of natural phenomena and the scientific practices used to generate, test, and revise those models. However, this type of instruction is difficult to successfully implement, especially for PTs who lack the knowledge, experience, and strategies to teach according to MBI. Specifically, it appears to be challenging for them to develop their own knowledge of scientific models and modeling (Windschitl, 2004; Justi & Gilbert, 2002), design MBI lessons (Schwarz & Gwekwerere, 2007), and attend to student thinking (Hayes, 2002). To address some of these challenges, I conducted a study to examine the changes in PTs’ knowledge of MBI and their ability to design MBI lessons in the context of a two-year teacher preparation program. In this chapter, I discuss the successes and challenges of helping PTs change their conceptions of MBI and lesson design in the methods courses with respect to the broader literature on lesson planning and design, particularly in science and mathematics. I then present the limitations and implications of my study, closing with some suggestions for areas of future research.
5.1 Preservice Teachers’ Knowledge of Inquiry and Lesson Design

My analysis of the PTs’ educational philosophy papers revealed that their initial ideas about science instruction were generally teacher-centered and did not incorporate key aspects of MBI. In many ways, my findings are similar to those of Hayes (2002) who found that it was challenging for most of his PTs to let go of a didactic approach to teaching and move towards lessons that considered the development of students’ own interest. I found, initially, that a typical lesson developed by PTs during the study was mostly teacher-centered. These lessons included teachers asking questions, followed by a lecture, and then guided practice, which ultimately revolved around the lecture material. In most cases, student participation during investigations, discussions, and independent study were merely used to confirm what teachers covered during lectures. Moreover, the majority of PTs in my study emphasized experiential learning through hands-on experiences and argued for the importance of real-life connections and motivation for students to learn (see Table 15). These ideas of science instruction in lesson designs implicitly pointed to the PTs’ views of instruction that was heavily directed by teachers.

Moreover, similar to the findings of Schwarz and Gwekwerere (2007), who saw that PTs could improve how they think about models but still struggled to incorporate models into their lessons, I found that initially only two PTs in my study mentioned the use of models as part of their instructions. These models were used to convey information, not as generative tools developed from students’ ideas, and different from how scientists use models (see Table 15). On the other hand, the PTs’ perspectives on instruction that were teacher-centered and did not incorporate modeling practices somewhat changed during the methods courses in two ways: (a) from teacher-centered
and experiment-driven lessons to lessons that focused on modeling, and (b) from scripted or procedural modeling to a more sophisticated modeling practice in which the target models were explicitly described (see Figure 7). Such lessons would likely promote more student engagement and modeling by allowing students to evaluate each other’s models and develop their own understandings. These changes were likely attributed to the experiences that PTs had as learners as part of a long and comprehensive sequence of intervention in the four methods courses. In particular, the extended inquiries in Methods I (see Appendix A), provided them with experiences to develop, test, and revise their own models.

However, contrary to Schwarz and Gwekwerere (2007), who found that PTs’ ideas of models were limited to representing objects or phenomenon, I found that PTs in my study developed a more sophisticated idea about models. For instance, Nina described how her idea of models changed from a representational model to a dynamic one, in which models were not only representations, but could also be used to generate questions, as well as test, predict, and explain phenomena as a central part of their lessons’ teaching methodology. In addition, contrary to the findings of Windschitl and Thompson (2006), who saw that their PTs were capable of developing a more sophisticated understanding of scientific models but did not use theoretical models to ground investigations in their inquiry projects, PTs in my study were able to identify appropriate big ideas in science and incorporate models as part of investigations in their lessons. Specifically, I saw that lessons designed as part of Methods III and Methods IV included: (a) activating and eliciting students’ prior knowledge, (b) designing and conducting investigations to test models, (c) evaluating evidence, and (d) discussing and revising student models (see
Figures 7-9). These changes hinted at improvements in the PTs’ knowledge of models and how to incorporate them in lessons.

It is worth noting that contrary to the PTs in the studies of Schwarz and Gwekwerere (2007) and Windschitl and Thompson (2006), who attended only one methods course in science, PTs in my study had an opportunity to learn modeling and lesson design in an extended period of time—four consecutive methods courses. However, the successes and struggles of PTs in my study in terms of their knowledge of models, modeling, and lesson design in Methods I (in one semester) were similar to those PTs in studies of Schwarz and Gwekwerere (2007) and Windschitl and Thompson (2006). Specifically, several lessons in Methods I did not incorporate the modeling process (see Figure 7). My findings suggest that this kind of learning takes time and that warranted careful scaffolding and multiple learning opportunities for PTs in several methods courses.

With regard to PTs’ considerations of students’ conceptions while designing lessons, PTs in my study lacked knowledge about students’ prior conceptions, difficulties, alternative conceptions, and prerequisite knowledge at the start of the program (see Figures 12-14). Furthermore, they did not consider these elements in their lesson designs in Methods I and II. These mirror the findings of Friedrichsen et al. (2009), who saw that their beginning teachers lacked ideas about learners, instruction, curriculum, and assessments, and did not consider these components in their lesson designs. On the other hand, my findings showed a shift from teacher-centered to student-centered lessons after PTs participated in the lesson design and redesign activities, an internship seminar, and reflection assignments in Methods III and Methods IV (see
As part of their lessons, PTs in my study began to consider students’ potential difficulties and alternative conceptions while selecting activities and evidence for use in their lessons (see Figure 13). They moved toward pedagogical approaches that involved students constructing knowledge themselves, which reflected the growth of PTs’ PCK of learners and instructional strategies.

I believe that the series of instructional activities in the methods courses contributed to the increase in PTs’ knowledge of MBI and awareness of students’ conceptions. Specifically, PTs in my study had an opportunity to review the literature to identify students’ alternative conceptions and difficulties as they planned their units in Methods II and Methods III, conducted action research projects in Methods III, and analyzed students’ thinking based on data collected during their internship seminar in Methods IV (see Appendix A). Such a sequence of activities provided PTs in my study with multiple scaffolded opportunities to analyze students’ conceptions, and in turn, helped them develop better MBI lessons. I also believe that these activities contributed to the development of PTs’ PCK (MBI as an orientation to teaching science, consideration of students, and instructional strategies) during their participation in the methods courses. My findings resonate with Gullberg et al. (2008) findings that their PTs showed awareness of the importance of embedding questions in their lessons to elicit students’ prior knowledge. In the same way, the methods courses in my study seemed to have helped PTs recognize the importance of appropriate questions that would elicit relevant student conceptions, including alternative conceptions, all of which can be used as leverages for accomplishing lesson objectives (see Figure 13). In addition, my study showed that PTs utilized students’ conceptions while selecting objectives, driving
questions, activities, investigations, and assessments for their lessons. PTs used their knowledge of students’ prior learning history (knowledge and skills) as leverages to build the new learning experiences in the lessons (see Figures 12 & 13). They used this knowledge to consider a sequence of topics in a unit (over a semester) and references to prerequisite knowledge that students must have prior to a given lesson (see Figures 13 and 14).

Regarding the other components of lessons, my findings showed a number of changes reflecting how PTs’ conceptualized lesson plans. Contrary to Duschl and Wright (1989), who found that teachers paid little attention to the scientific theories involved in lessons, my findings showed that PTs were able to focus on the big ideas in science while engaging in lesson designs. Specifically, these included shifts toward designing lessons with: (a) goals and objectives that incorporate scientific phenomena with causal explanations (see Figure 1), (b) objectives that are measurable and performance-based (see Figure 2), (c) motivational structures that are likely to be interesting for students (see Figure 4), (d) driving questions that would be productive in eliciting relevant students’ prior conceptions at the start of each lesson (see Figure 4), and (e) assessments that are more comprehensive and relevant to identified objectives (see Figure 5). These shifts pointed to the development of PTs’ understanding of MBI components of curricula and assessments of student learning. In many ways, PTs indicated their use of the modeling processes as a way to assess or monitor students’ progress as part of their lesson designs. In particular, they mentioned students’ naïve models and explanations as forms of formative assessment, and tests and projects as types of summative assessments, which pointed to an increase in PTs’ PCK of assessments of student learning (see Figure 5).
I acknowledge that despite the improvements that PTs in my study showed in the methods courses, learning had been challenging for them. PTs’ knowledge about MBI and their students did not exhibit continuous positive change. Specifically, Figure 7 shows a regression of sophisticated modeling practice from Methods III to Methods IV. I also found similar regression from Methods III to Methods IV with regards to student-centeredness of lessons (see Figure 10), PTs’ knowledge of students’ conceptions (see Figure 11), and PTs’ identification of leverages in lessons (see Figure 13). I am not really sure why, but the lack of progress maybe due to the PTs’ learning curve in the methods courses as they negotiated what they learned from their previous courses while at the same time questioning the feasibility of implementing MBI in the classroom. My study supported the findings of Windschitl et al. (2008) that showed that learning MBI, designing MBI lessons, and engaging students are challenging for PTs.

In addition, PTs in my study encountered two main difficulties in designing their MBI lessons: (a) embedding argumentation as part of scientific practice and (b) providing suitable or adequate evidence for students to use as part of their investigations. In most cases, PTs ended the inquiry process in their lessons by asking students to revise their models and present them in front of their classmates without any follow up argument or discussion around models and evidence (see Figure 7). PTs did not use evidence to inform their discourse about the models. In addition, the evidence that PTs provided was either too complicated or provided too much information that could be simply extracted from a document without analysis (see Tables 17 & 18). My findings confirmed what Windschitl et al. (2008) found with their PTs as they engaged, initially, in modeling and argumentation at the beginning of their methods course. Specifically, they also saw that
the majority of their PTs mentioned discussing or stating what they learned from their experiments instead of using evidence and models to anchor their arguments.

In summary, similar to the findings of Hayes (2002), who saw that his PTs struggled to let go of didactic approach to teaching, typical lessons described by PTs in my study contained experiential learning to confirm teachers’ lecture material. My study findings supported the findings of Gullbert et al. (2008) that described that PTs are capable of developing productive questions that elicit relevant student conceptions. However, contrary to study of Windschitl and Thompson (2006), who saw that PT’s were capable of developing more sophisticated understanding of models but failed to ground their inquiry investigations, PTs in my study seemed to develop better view of models—from representational to dynamic models. Moreover, contrary to the findings of Friedrichsen et al. (2009), which showed that beginning teachers lacked ideas about learners and did not consider them in designing lessons, PTs in my study were able to develop student-centered lessons, considered students’ conceptions, and identified learners’ history while designing their lessons. My study findings seem to support the idea of a longer intervention, namely four consecutive science methods courses instead of just one, to allow learning to happen more gradually, through careful scaffolding of activities that provide PTs with knowledge of MBI and ability to design lessons. However, despite the successes of PTs in my study, my findings suggested that they also struggled to embed argumentation and provide suitable evidence as part of MBI. Table 19 contains a summary of my research findings.
Table 19. Summary of Research Findings

<table>
<thead>
<tr>
<th>Previous studies showed that…</th>
<th>My research findings described that…</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PTs’ struggled to let go of lecture-approach to teaching (Hayes, 2002)</td>
<td>1. Lessons, initially, focused on experiential learning to confirm teacher’s lecture material.</td>
</tr>
<tr>
<td>2. PTs’ developed awareness and importance of guiding questions in lessons to elicit students’ prior knowledge (Gullbert et al., 2008)</td>
<td>2. PTs’ developed productive questions that elicit relevant student conceptions.</td>
</tr>
<tr>
<td>3. PTs’ were capable of developing more sophisticated understanding of models but failed to ground their investigations (Windschitl &amp; Thompson, 2006)</td>
<td>3. PT’s seemed to develop better view of models: from representational to dynamic (predict).</td>
</tr>
<tr>
<td>4. Teachers paid little attention to scientific theories involved in lessons (Duschl &amp; Wright, 1989)</td>
<td>4. PTs were also able to identify appropriate big ideas and incorporate models as part of investigations in lessons.</td>
</tr>
<tr>
<td>5. PTs’ lacked ideas about learners and did not consider them while designing lessons (Friedrichsen, et al., 2009).</td>
<td>5. There were shifts from teacher- to student-centered lessons: modeling practices and identifying students’ alternative conceptions.</td>
</tr>
<tr>
<td>6. PTs, initially, had difficulties in modeling &amp; argumentation (Windschitl et al., 2008)</td>
<td>6. It was challenging for PTs to embed argumentation and prove suitable evidence as part of MBI.</td>
</tr>
</tbody>
</table>

5.2 Limitations

My study has several limitations. First, lesson design is only one of many ways of looking at teaching practices. It may not be an accurate reflection of what PTs’ instruction would look like in the classrooms. However, lesson design is not only common to all teaching, but it is also one of the core teaching practices promoted in pre-service methods courses, and therefore, there is still value in studying lesson planning in teacher education. Secondly, this study did not include an assessment of PTs’ own
content knowledge in the domain (biology) as they participated in the methods courses. Domain-specific knowledge likely had an effect on the teachers’ abilities to design MBI lessons, which was not described or accounted for in this study. Third, my analysis and codes did not account for the quality or correctness with regards to the science concepts in PTs’ responses. Finally, since I did not collect data (observation or video recordings) during the internship seminar, I am unable able to describe how PTs implemented their lessons in the classroom.

5.3 Implications for Preservice Science Teacher Education Programs

My research findings suggest ways to engage PTs in MBI and help them implement its components while designing science lessons. Teacher-educators can better prepare preservice science teachers in planning for inquiry-based instruction by providing them with knowledge and experiences of inquiry that focus on science as model-building and -testing. This entails developing PTs’ own knowledge of MBI and placing an emphasis on students’ active role in scientific practice. These tasks are challenging to do, particularly for PTs who lack the knowledge of MBI and repertoire to design MBI lessons. My research findings showed that learning takes time, and one methods course in science is insufficient to change PTs’ knowledge and practice with regard to lesson design and students’ conceptions. Fostering knowledge of MBI and lesson design involves careful scaffolding of activities in consecutive methods courses. Specifically, PTs in my study had a chance to experience MBI as learners and conduct clinical interviews with students to elicit students’ conceptions in Methods I, design units and lessons in Methods II and Methods III, conduct action research projects in Methods III,
and analyze students’ thinking based on data collected during their internship seminar in Methods IV. On the other hand, despite our efforts, PTs in my study struggled to incorporate argumentation as part of scientific practice in the classroom and to provide adequate evidence for their students to use during investigations. One of the possible ways to address these challenges is to engage PTs in MBI in their methods courses with particular attention to the critique and revision of teacher-provided evidence in their lessons. This can be done by providing PTs with a number of examples of evidence or data collected by the teacher-educator or from previous cohorts of PTs, about how students responded to teacher-supplied evidence in a lesson. PTs can evaluate and revise these evidence sets as well as reflect on identifying suitable evidence and potentially challenging evidence (what kinds of evidence are challenging for students and why). Analysis and revision of evidence can also be done during their teaching internship. In addition, even though PTs in my study were exposed to argumentation in their methods courses, careful attention should be given to differentiate argumentation from presentation of ideas as well as to use evidence and models as part of argumentation while designing inquiry lessons.

Secondly, my research findings showed the importance of helping PTs design instruction that incorporates MBI and considers students’ prior conceptions and skills. Specifically, this includes assisting PTs to become aware of students’ conceptions. This can be done by engaging PTs in lesson design, reflection, and revision activities in the methods courses to help them develop their PCK of MBI instruction. PTs can also conduct a literature review to identify what students at a particular age or grade level know or are able to do as part of the lesson objectives. In addition, PTs can gain
experiences with students during their teaching experiments in the methods courses, which my PTs have done in this study. These exercises have the potential to foster growth in PTs’ PCK of students as they reflect on learners’ knowledge, skills, and difficulties. By increasing their awareness of students, PTs would be able to design instruction that is more student-centered—in particular, lessons that incorporate (a) eliciting students’ prior knowledge, (b) engaging with scientifically-oriented questions, (c) making connections to scientific knowledge, (d) modeling, and (e) justifying explanations. In the next section of this work, I discuss possible areas for future research.

5.4 Future Research

Based on my findings, three areas of study warrant further research: (1) an examination of PTs’ successes, struggles, dilemmas, and design decisions as they progress through designing MBI lessons or unit; (2) an assessment of PTs’ domain specific knowledge and its relationship to lesson design; and (3) an examination of teachers’ enactments of their MBI lessons in the classroom. A qualitative study approach may be used to identify and describe the struggles, successes, dilemmas, and design decisions encountered by a group or groups of PTs as they progress through the process of lesson or unit design. This study can be done via a video-case study during which PTs engage in the design milestones of identifying appropriate learning goals, characterizing students’ prior knowledge in the domain, identifying a problem context for a given unit of study, developing a unit outline, and finally, developing a full set of activities and assessments for their inquiry lessons. This research might investigate excerpts in the videos in which PTs experienced varying degrees of difficulty in terms of meeting
selecting evidence or investigations in the lesson. Another study might also look at the extent to which PTs’ domain-specific knowledge contributes to the design of MBI lessons. This research may uncover the relationships or complexities among PTs’ content knowledge in biology, PTs’ conceptions of MBI, and lesson design.

Areas investigated in my work can also be expanded through an examination PTs’ enactment of lessons in the classroom during their internship seminar or as beginning teachers. In particular, a future study may look at the fidelity of PTs’ planned lessons, changes made during instruction, and the rationale for these changes. Changes or instructional revisions by PTs may be due to their response to students’ prior conceptions or models, students’ response to particular investigations, time and resources, and other factors. A study such as this may describe how PTs attend to and adjust instruction based on students’ thinking or models. Moreover, this research might also look at the extent to which MBI is enacted by PTs as part of their instruction.

Finally, a study might examine PTs’ classroom implementation of MBI during their induction program after they completed their certification program. This would provide opportunities for PTs to gain more knowledge and experiences in the classroom while implementing what they learned from their methods courses. Such a study might examine the successes and challenges of induction teachers, as well as the strategies they made to implement MBI. Finally, this study could also examine their lesson designs as they gained more knowledge and experiences with regards to students’ conceptions and difficulties.
References


Appendix A

The Four Methods Courses

Methods I

The first methods course, Biology and Society, is a 3-credit course that meets once a week for 160 min (15 weeks). This course aimed to deepen PTs’ understandings about model-based inquiry practice that included scientific model building and argumentation. This course provided PTs with experiences of inquiry as learners and helped them develop a vision of MBI instruction. Towards these ends, the course was divided into four sets of lessons, activities, and assignments. The first activity set lasted four weeks and was composed of three lessons focused on modeling and argumentation. For example, in the “mystery tubes” activity, PTs generated and revised models depicting the arrangement of hidden strings inside the tubes based on the behavior of the strings when pulled. This activity allowed students to develop models, conduct experiments to test their models (collect data and look for patterns to describe the behavior of strings), and defend their models. Moreover, this activity fostered a discussion of how their modeling experiences are similar and different to how scientists do science. In particular, one PT argued that it is different because phenomenon in science changes whereas the tubes stayed the same. While another PT argued that phenomenon stayed the same as models changed. In general, most PTs agreed that what they did was similar to what scientists do except for time and resources of teachers in classrooms (scientists spend more time to test models, have more resources, and take longer to publish their work). In another activity, PTs developed arguments about whether dinosaurs were warm or cold-blooded given a set of evidence provided to them. Common to these activities was a
focus on scientific practices in contexts that are not demanding in terms of content; thus we refer to this activity set as simple inquiries.

The second activity set, the cancer unit, was an extended inquiry (three weeks) in which PTs developed models of the molecular basis of cancer using multiple pieces of evidence that we provided, such as scientific studies about genes and proteins involved in cancer, to evaluate and revise their models. The topic of cancer was selected to allow PTs to experience, as students the successes and difficulties of learning a conceptually challenging content through inquiry (just as their future students would be). PTs evaluated models and evidence to describe if cancer is a result of a mutated gene and/or caused by aneuploidy (other than mutations).

The last three-week activity set, the lead poisoning unit, involved three intertwined activities in the context of a middle school unit on membrane transport mechanisms in which middle school students investigated how lead enters the cell – the first step in lead poisoning. This unit was designed for middle schools as part of the Promoting Reasoning and Conceptual Change in Science (PRACCIS) program, a National Science Foundation (NSF) funded project. The unit was implemented in a seventh grade science classroom by one of the participating teachers in the NSF project; video recordings of the implementation as well as examples of student work from the unit were used in the third activity set. The PTs concurrently engaged (as learners) in select activities from the lead poisoning unit, viewed videos of the middle school teacher working through those same activities with her own students, and analyzed student work from those same activities. The goal in this activity was to provide a coordinated inquiry experience that toggled between the perspectives of the learner and the teacher. For
example, in one of activities the PTs developed a model of osmosis, watched a discussion of students’ osmosis models in the middle school classroom, and analyzed examples of those students’ osmosis models. While the content for this unit was familiar to the PTs, none actually knew how lead enters the cell.

In addition to the MBI activities, PTs engaged in lesson critique and revision (Duncan, Pilitsis & Piegaro, 2010). The goal of this activity was to help sharpen the PTs’ understanding of what teaching modeling and argumentation in science might look like (vision of MBI practice) and what might be the shortcoming of existing instructional materials. The pedagogy of lesson critique and revision builds on the authentic teaching task of adapting instructional materials (Davis, 2006). PTs critiqued three lessons based on a set of 5–7 criteria developed individually and then as a whole class. The PTs applied the criteria to lessons that were given to them and that reflected a continuum of less to more inquiry-oriented (the research team selected these lessons from books and the internet). Lesson critiques and revisions were designed to enhance PTs’ understanding of inquiry-based lessons and their design (Crawford, 1999; Duncan, Pilitsis & Piegaro, 2010; Schwarz & Gwekwerere, 2007). The table below lists the lessons, activities, readings, and assignments as indicated in the course syllabus.

<table>
<thead>
<tr>
<th>Week 1- Introduction</th>
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<tbody>
<tr>
<td>Write your Teaching Philosophy Paper</td>
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<tr>
<th>Week 2- Lesson Critique I</th>
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</table>

Week 3- Scientific modeling

Week 4- Scientific argumentation

Week 5- Model-based inquiry: introduction
Windschitl, M & Thompson, J. Teaching about science ideas as models. *University of Washington* (1-11)


Week 6- Lesson critique II

Week 7- Inquiry into cancer I

Week 8- Inquiry into cancer II
Inquiry project proposal due

Week 9- Inquiry into cancer III

Week 10- Inquiry project interlude and the evolution debate
*Scientific American*, "Chromosomal Chaos and Cancer," by Peter Duesberg, May 2007, p. 52-59 [access online via library].

Week 11- Model-based inquiry in the classroom I
Revised inquiry proposal (with initial findings, if any) due.

Week 12- Model-based inquiry in the classroom II

Methods II

The second methods course, Teaching Life Science, is a 3-credit course that meets once a week for 15 weeks. This course aimed to develop the practices of instructional planning and implementation of MBI. Methods II was essentially a design-based course in which PTs, in small groups, developed extended (2-3 week long) model-based inquiry units about selected topics in biology such as photosynthesis, ecosystems, etc. The project developments were conducted in small groups during weeks 2-13 of the course. Lessons and activities in this course were scaffolded to increase PTs’ repertoire in analyzing students’ prior conceptions and alternative conceptions (Crawford, 1999), decision strategies involved in incorporating models and modeling in lesson design (Schwarz and Gwekwerere, 2007), incorporation of epistemological bases of scientific knowledge in lessons (Duschl & Wright, 1989; Windschitl & Thompson, 2006), and experience in teaching inquiry (Windschitl, Thompson, & Braaten, 2008).

In this course, PTs were introduced to several design frameworks including Learning for Use (Edelson, 2001) and Backwards Design (Wiggins and McTighe, 2005). The design work involved several “milestones” and lasted the entire semester. These milestones included identifying appropriate learning goals, interviewing students to
identify common prior conceptions, developing a problem context for inquiry lessons/units, and developing an entire set of lesson plans and assessments. PTs were given a lesson plan template to guide them in designing their lessons. The lesson plan template included the following components: (a) overview of the lesson, (b) lesson objectives, (c) relevant student misconceptions, (d) standards, (e) materials and preparation, (f) notes to the teacher, (g) activities, and (h) assessments. PTs had a chance to develop each component of their lesson design with a particular focus on student’s prior knowledge. To this end, PTs developed and conducted small number of clinical interviews with students, which were done in weeks 2 and 3 of the course. The goal of this assignment was to help them design instruction that builds on students’ prior knowledge. Before conducting interviews, PTs read and discussed existing literature to identify students’ conceptions in the domain. Specifically, PTs identified students’ prior knowledge (guided by the literature, experiences, and intuitions), listed performances that they expected from students, and described concepts and skills that potentially be challenging for students. In terms of preparing for their interviews, PTs identified their target science concepts, conceptions they would like to know from students, and evidence of performances they expected from students. They used interview probes or tasks such as asking students to draw diagrams/models, critique explanations, teach a concept, etc. to elicit students’ prior knowledge (Driver et al., 1994).

After their clinical interviews, each group in weeks 4-7 identified and developed the learning progression for their project. This included the learning objectives and rationale, synopsis of the clinical interview analyses and how they informed the design of their project, the choice of context or problem, and an outline of the project progression.
By week 8, PTs had a chance to critique each other’s project backbones using the criteria that they developed in Methods I. Then they revised their unit based on each other’s critiques, designed lessons, and developed assessment plan for their unit. They presented their projects in week 13 of the course.

The second major activity in the course included a 30 hours of classroom observations. The goal of this activity was to help PTs become familiar with science classrooms in public schools. In particular, for them to learn the different ways teachers manage their classrooms, observe various social contexts (student-student and teacher-student interactions), expose them to the different teaching approaches employed by teachers, and become familiar with the resources available in science classrooms. As part of their practicum experiences, PTs observed multiple teachers, taught one lesson during weeks 12 and 13 of the course, and kept a journal to document and reflect on their experiences. In their teaching experiments, PTs prepared and taught one lesson that focuses on modeling and argumentation. They collected audio-recordings from their students, and used quotes from transcripts to support claims in their presentation and reflection paper. The table below lists the lessons, activities, readings, and assignments as indicated in the course syllabus.

<table>
<thead>
<tr>
<th>Week 1: Introduction</th>
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<tbody>
<tr>
<td>Become a member of NSTA (National Science Teachers Association)</td>
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<tr>
<td><a href="http://www.nsta.org">http://www.nsta.org</a> or of NABT National Association of Biology Teachers</td>
</tr>
<tr>
<td><a href="http://www.nabt.org">http://www.nabt.org</a></td>
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<table>
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<tr>
<th>Week 2- Clinical Interviews</th>
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</table>

**Week 3- Clinical Interview**  
Read 2 articles about student conceptions regarding your topic

**Week 4- Design Frameworks**  


**Week 5- Project Context and Backbone**  

**Week 6- Project Backbone continued**

**Week 7 - Finalized Project Backbone**

**Week 8- Unit Critique**  


**Week 9- Interlude: Technology fair**  

**Week 10- Lesson Plans**

**Week 11 Interlude- Teaching experiment preparation**  
Methods III

In Methods III, PTs further developed their abilities to teach inquiry-based lessons and assess students’ thinking during their supervised student teaching internship, which lasted 15 weeks. The two main goals of this course were to support PTs’ teaching experiences and for them to learn how to be critical and analytical about their MBI teaching practice. In this course, PTs were given two opportunities to plan, implement, and critically examine extended model-based inquiry lesson sets. The first lesson set was done in weeks 4-7 and involved a 1-2 day inquiry lesson focusing on at least two model-based inquiry teaching strategies, while the second was done in weeks 10-14 and entailed a week-long model-based inquiry unit involving all the main elements of MBI.

PTs recorded their second lesson set and shared and discussed an excerpt of the video in the course. As part of this assignment, PTs critically analyzed student learning in the lesson sets and reflected on their plan and implementation. PTs collected student work (worksheets, models, tests, etc.), analyzed them according to particular dimensions (modeling, argumentation, evidence, etc.), and came to class to discuss them. These

<table>
<thead>
<tr>
<th>Week 12- Lesson plans</th>
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<tr>
<th>Week 13- Final Project Presentations</th>
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| Week 14- Teaching experiment |

| Week 15- Interviews |
examinations of student thinking were held in weeks 3 and 4. This course provided PTs’ an opportunity to actually implement the pedagogical approach, MBI, which is at the core of the certification program.

In week 8, PTs had a chance to experience MBI that was focused on analyzing evidence. Specifically, in the *Life on the Greenland Ice Pack* lesson, PTs used food web models and evidence to understand the relationships among the different organisms in the ice-cap. Arctic geologists have developed two alternate food web models to describe how microscopic plankton, arctic salmon, ringed seals, artic foxes, and polar bears survive in extreme low temperature (see diagrams below).

```
Food Web A

Polar Bear

Ringed Seal

Arctic Salmon

Food Web B

Polar Bear

Ringed Seal

Arctic Fox

Arctic Salmon
```

PTs examined the different evidences from a hotel owner, fisherman photographs, research study, and survey to evaluate the models (see diagrams and data in tables below). This activity fostered discussions and examination regarding the strengths and weaknesses of each evidence. For instance, as part of evidence 1, the number of guests who collected data on animals was unclear, the expertise of the guests (if they can identify the different animals) was not mentioned, and it did not describe how guests collected their data. Evidence 2, on the other hand, seemed to be moderately accurate.
Though the sample in the second evidence was relatively small and did not mention how many seals polar bears eat, it indicated that polar bears eat seals. While evidence 3 can be used to support either model—food web A explained the evidence by asserting that changes in salmon affected seals and thus indirectly affected foxes, while food web B explained the evidence by asserting that changes in salmon directly affected foxes. In general, this activity fostered discussions regarding the importance and use of evidence in MBI.

Another important activity in Methods III was the development of action research project, which was introduced in week 5 and a follow-up discussion in week 11. This
project aimed to examine the PTs’ own teaching practice. Each group identified research questions that were interesting for them. They cited relevant literature and personal experiences that relate to their research questions. They also developed a theoretical model of the issue that explained their hypothesis and courses of action (methods and data collection/analysis procedures). The PTs’ action research projects were continued and revisited in Methods IV. The table below lists the activities and readings in Methods III.

<table>
<thead>
<tr>
<th>Week 1- Getting started</th>
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<tr>
<td>Expectations of internship</td>
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<tr>
<td>VNOS</td>
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<table>
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<tr>
<th>Week 2- Lesson Set 1 part I</th>
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</thead>
<tbody>
<tr>
<td>Bring in curriculum plan for the semester (you need to select an enactment date for Lesson Set I)</td>
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<tr>
<td>Work on Lesson Set I (draft due next week)</td>
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<tr>
<th>Week 3- Examining Student Thinking Part I</th>
</tr>
</thead>
<tbody>
<tr>
<td>We will analyze student responses to VNOS</td>
</tr>
<tr>
<td>Lesson Set I- to be critiqued by classmates</td>
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<table>
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<tr>
<th>Week 4- Examining Student thinking Part II</th>
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<tbody>
<tr>
<td>We will analyze video of student group work and whole class discussions (Annenberg)</td>
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<tr>
<td>Revise and enact Lesson Set I</td>
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<tr>
<th>Week 5- Research Interlude</th>
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<tbody>
<tr>
<td>Reading: Action Research</td>
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<tr>
<td>Eileen Ferrance (LAB)</td>
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</tbody>
</table>
Determine research questions as class
Choose a research question (pairs) begin work on research proposal
Research proposal due end of the week

Implement Lesson Set I

**Week 6- Professional Development and Creating a Portfolio**

What do you need for your teaching portfolio?

Reflection of Lesson Set I due next week

**Week 7- Lesson Set 1 Part II**

Bring examples of student work from Lesson Set 1- bring your reflection

Revise reflection on Lesson Set I – due by end of week Sat 5pm.

**Week 8- Student Thinking Part III**

We will simulate a class lesson and analyze it.

Due by the end of the week draft of Lesson Set II send to peers and post

**Week 9- Lesson Set II Part I**

Discuss and revise Lesson Set II

Implement Lesson Set II as soon as revised

**Week 10- Café Connect**

Implement Lesson Set II

**Week 11- Research Interlude**

Discuss development of instruments and touch base about research design and implementation

Implement Lesson Set II

Draft of reflection paper on Lesson Set II due Mon in class when you are presenting

**Week 12Examinating Practice I**

**Week 13 - Examining Practice II**

**Week 14 - Examining Practice III**

**Week 15- Continue Presentations**
Methods IV

The goals of the final course, Methods IV, were to develop the PTs’ skills as reflective practitioners, revise one of the lesson sets, and create a teaching portfolio that they could use in their job interviews. The class met three hours once a week for 15 weeks. One of PTs’ assignments was to continue their action-research projects from Methods III that they collected data during their student teaching. As part of their project, each group conducted a literature review that included summary or prior research (from journal articles or book chapters) that relate to their research question. PTs designed methods to answer their questions, analyzed student work, shared their results in a 10-minute presentation, and discussed instructional implications. For instance, one group mentioned that it was insightful to see what students’ learned based on their revised models, while another group said that it was challenging for students to include explanations and mechanisms in their models.

The second major assignment was revising one of the lesson sets PTs developed in Methods III. The unit included at least one laboratory session, focused on modeling and argumentation, and components of lesson plans (overview, objectives, standards, instructional methods, and assessments). PTs revised their lesson sets or units based on their experiences in implementing lessons and critique that they received from one of their classmates. The final assignment involved developing a teaching portfolio that they could use during their job interviews. This included their teaching philosophy statement, unit plan, sample lesson and assessment that they implemented in Methods III, examples of student work, reflection on lesson implementation (focused on student thinking), professional development plan, and curriculum vitae. These components aimed to show
evidence of good instructional practices, an understanding of key learning theories in science instruction, understanding of students’ thinking, and commitment for continuous professional growth. The table below lists the activities and readings in Methods III.

<table>
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<tr>
<th>Week 1- Introduction</th>
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<th>Week 2- Incorporating data into model based units</th>
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<th>Week 3- Teacher research I</th>
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<th>Week 4- Teacher research II</th>
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<th>Week 5- Lesson critique</th>
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<th>Week 6- Teacher research III</th>
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<th>Week 7- Informal education</th>
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<th>Week 8- Role play- managing an inquiry classroom</th>
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<th>Week 9- Inquiry versus direct instruction: a recent debate; and lesson revision</th>
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**Week 10 - Research III**

**Week 11 - Data analysis and discussion**

**Week 12 - Final project poster presentation**

**Week 13 – Find a job**

**Week 14-15 Interviews**
Appendix B

Assignment Guidelines for the Educational Philosophy Paper

Individually prepare a statement (min 750 max 1000 words 12 point font) about your perspective on the following four issues:

1) What are the goals of biology education and what should we be teaching at the high school level?

2) Briefly, what are the problems with current instructional methods?

3) What are the best ways to learn and teach science and how do I know this?

4) Describe an ideal lesson in biology.

Please use headings for your response to each question. Make sure to label the file properly with your name and assignment title.
Appendix C

Example Educational Philosophy Paper

Jake, Methods I

1) What are the goals of biology education and what should we be teaching at the high school level?

The goals of biology education should be similar to the goals of any subject, namely to get student's interested in the material and thinking on a higher cognitive level. However, there are specific principles that any student who has completed a high school biology course should be familiar with. These principles include the different cell types and their structures, mitosis and meiosis, how DNA serves as the carrier of genetic material, evolution, taxonomy and physiology amongst other topics. Students should also learn proper lab techniques and be expected to write several full lab reports in the same format as those in a scientific journal. Ideally, what is being taught at the high school level should be similar to what is being taught in college, just at a slower pace and not as in depth in some areas. The primary objective of a high school biology class should be to prepare students for an intensive college biology course.

2) Briefly, what are the problems with current instructional methods?

The problems with current instructional methods are wide ranging, but it is a reluctance to challenge students that is typically behind poor teaching. When teachers simply equate memorization with learning, they promote a narrow mind frame by which students are unlikely to remember much past the next test. There is also a failure on the part of teachers to motivate their students and get them enthusiastic about learning. While some teachers deride their students for being inattentive, tedious instruction makes it difficult for even the most cognizant student to be engaged. By just lecturing and showing textbook figures it is doubtful that teachers can generate much curiosity from their students, unless they have a strong prior interest in the subject matter.

3) What are the best ways to learn and teach science and how do I know this?

When discussing the best ways to learn and teach science, I can only speak from my experience as a student of science. In general, I have found that the more I apply the subject matter, the better I learn it. This can be accomplished several ways, such as relating topics to everyday life, coordinating lessons with labs and asking questions where the answers are not readily apparent. These methods are also a means to get students interested in the material, which is the most critical aspect in determining whether or not learning will take place. When students see the relevance of what they are being taught to their own life, it encourages them to seek further knowledge. Biology is a subject that can provide us with a better understanding of ourselves and our world, so when educators are able to effectively take advantage of this, most of their students will take the initiative to learn the material.
4) Describe an ideal lesson in biology

An ideal lesson in biology consists of more than just a teacher lecturing while their students sit idly by. Without any specific topic in mind, it would be useful for a teacher to begin class with a compelling question or example relating to the lesson and getting input from the class. The subsequent lesson should follow a logical order and be accompanied with text, along with images, to illustrate what the teacher is talking about. In addition, there are thousands of short videos online, which can be shown to demonstrate many processes in biology. Models, samples and demonstrations are also useful visual aids to present the class. Furthermore, the teacher should ask the class questions periodically on what they had gone over in order to make sure students are following along. Utilizing a system whereby students can answer multiple-choice questions with hand-held device that transmits their response to a computer, is a great way to get every student to participate in class. By asking follow-up questions the students can continually review the material and the teacher can find problem areas where they need to elaborate further on. The content of the lesson itself should contain numerous real life examples and facts that would intrigue students, but be focused on a particular topic. The overall idea behind this lesson plan is to be able to convey all the information in a lecture without the monotony of a teacher just lecturing.
Appendix D

Interview Protocol

Instructions to interviewees:
- Give as much information as possible; answer, even if you are not sure - guess.
- Use what you have learned in class.
- You can add from personal experience if relevant.

Instructions to interviewer:
- Italicized fonts are information for you. In some cases I suggest a further question.
- Make sure the interviewee exhausts their knowledge. Keep asking “anything else?” until they do not have anything else to add. There are several points in the interview where I note that you should ask “anything else?”
- Give them time to think. Interviewees may look stumped or stuck but give them time. Just smile and wait until they say something (it may feel odd but it is OK).
- If you can, try to take notes of the main points of their responses in the provided text boxes. Save this template with the student’s name “interview bio & Soc 07 NAME” so that you always have a clean copy of the interview protocol.

Task I – Scientific Inquiry:

1. Please quickly draw a model of scientific inquiry. Explain it.
   a. Ask the student to explain parts of the model and their relation.
   b. Ask them to define scientific models and scientific argumentation if they mention these elements.

2. What are the challenges that students have when engaging in scientific inquiry?
   a. Make sure students explain how they know about the challenges they suggest. So if they say students struggle with model building have them explain this further and provide evidence.

Task II – Lesson Critique:

Show the student the lesson plan. Have them read it through silently. Once they are done ask:

1. What are the three things you feel are good about the lesson?

2. What are the three things you feel are problematic (choose the most problematic ones if there are more than three). Why are they problematic?

3. Is this lesson an inquiry lesson? Explain your answer.
4. Suggest one or two changes that would make it more inquiry.
   a. Make sure they explain why those changes will make it more inquiry.

Task III – Design a Lesson

Tell students they are asked to design an instructional unit (can be more than one 45 minute period). The lesson must meet the following learning goals:

Give them the paper with the goals of the relevant version.

You have the following learning objectives:

- Students will be able to explain how plants convert light energy into chemical energy through the process of photosynthesis.
- Students will be able to identify the inputs of the process as carbon dioxide and water (and light) and the outputs are glucose and oxygen.
- Students will be able to explain that plants then use the glucose as a source of energy.

- Students will be able to explain how animals get their energy by breaking down glucose through the process of respiration.
- Students will be able to identify the inputs of the process are glucose and oxygen and the outputs are carbon dioxide and water (and energy).
- Students will be able to explain that animals get the glucose from their food.

What activities would you do to help students learn this (design a lesson sequence)?

Task IV – Evaluating Student Work and Instructional Implications

Tell students that they will be evaluating three student-made models and explanations (middle school student). You should evaluate both content and modeling. Show interviewee models and let them think for a minute. Ask interviewee the phenomenon in question (if they get it wrong correct them).

Version A - Cut models.
Students were asked to draw models of what happens after a cut heals. This followed a lesson on cell division.

Version B - Iceberg models.
Students were asked to draw models of what happens when water freezes and forms ice on lettuce (iceberg). This followed a lesson on phase changes in water.

1. Show the interviewee the student models and ask him/her to critique them.
a. What is good about these models? Be specific.

b. What is problematic about them? Be specific.

2. What would you do in class the next day if these were naïve? Explain what and why.

3. What would you do in class the next day if these were revised? Explain what and why.
## Appenidix E
### Example Interview Transcript
**Ava, Methods I**

<table>
<thead>
<tr>
<th>INTERVIEWER</th>
<th>Can you please draw a model of inquiry?</th>
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<tbody>
<tr>
<td>Ava</td>
<td>So, the first thing that really starts inquiry is a question. The student will come up with a question based on a reading or a discussion. From there they will jump into further research or set up an investigation, collect data. Once the data is collected the student may realize that they need to set up more experiments, but once the data is collected they will analyze results and go back to their initial question to see if it answers it. If not than they may want to set up an investigation to get more data. If it answers it, they may collect further research on a new question and the results from this experiment can be shared with the community to lead to argumentation but they may want to investigate it more for further data.</td>
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<thead>
<tr>
<th>INTERVIEWER</th>
<th>What do you think are the challenges that students have when they are engaging in scientific inquiry?</th>
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<tbody>
<tr>
<td>Ava</td>
<td>Problems?</td>
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<thead>
<tr>
<th>INTERVIEWER</th>
<th>Yes.</th>
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<tr>
<td>Ava</td>
<td>You can really… you need to make sure that you question is defined well because you can go off on tangents on things or it may be something that is too broad so there may be too much information that you can’t narrow the topic down. They can’t look at the big picture. It has to be a global kind of question to find information that can be extrapolated down. The idea of once you have an investigation set up, it has to be due able. Once we see it all laid out that we know if we were to carry it out than these would be the changes.</td>
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<tr>
<th>INTERVIEWER</th>
<th>Anything else?</th>
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<tbody>
<tr>
<td>Ava</td>
<td>I think that the first time doing it, they will be used to getting a lot of direction.</td>
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<tr>
<th>INTERVIEWER</th>
<th>Next task, I am going to give you a lesson plan. Take a minute to look it over and then I am going to ask you a couple of questions about it.</th>
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<tbody>
<tr>
<td>Ava</td>
<td>Okay.</td>
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<tr>
<th>INTERVIEWER</th>
<th>What are three things you liked about this lesson?</th>
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Ava  Three things…mm… I like the interaction that they have, it is a bit more hands-on first they get to try the rolling of the tongue part so it gets them all jazzed up. Then you give them things to play with sort of like money so it will keep them a little more interested. As long as you have something to do with your hands, it will make you more mentally stimulated because you are not just sitting there statically. Another thing that I like, I like that they show what would be the real children isn’t what you always see in the punnett square. I don’t think that they necessarily think that is what they are going to get but this demonstrates to them that doesn’t mean that you are going to get 1, 2, 3, 4 in a row.

INTERVIEWER  Anything else that you like?

Ava  I am glad that there is set list of goals. That is one of the things that we always like to see in the plans.

INTERVIEWER  Okay, what are three things that you don’t like in this lesson?

Ava  I think it really jumps to complex, alright they are leaning dominant traits and then it jumps to gametes and it doesn’t really. With one lesson plan it doesn’t really say where the students are at, where their prior knowledge is. Are they just sort of on genetics or have they learned reproduction. Usually with dominance, you start with peas and Mendel and this is jumping into children. And it seems like a lot, is this one days worth of work?

INTERVIEWER  Yeah, I am assuming that it is.

Ava  I think even you just want to work on the concept of the big A and the little a to show how you represent dominant and recessive.

INTERVIEWER  Anything else?

Ava  I do like when it asks them if their hypothesis was supported by the data or not because then they have to get into justification and explaining, but to write a lab report of what they did, I think that it is pretty explanatory. When they have to explain the difference in ratios is good but I don’t think they need to write out how they flipped the coins.

INTERVIEWER  Do you think this is an inquiry lesson?

Ava  Based on the model, I would say no.

INTERVIEWER  Why not?

Ava  They are given everything. They are asked about. First, they are asked (reads lesson plan to herself)…it is a little more guided for it to be inquiry. They need to come up with the experiment themselves. It just sort of ploughs right
through the material and I think that they are still being told most of it instead of learning on their own.

<table>
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<tr>
<th>INTERVIEWER</th>
<th>Anything else?</th>
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<tr>
<td>Ava</td>
<td>No, that’s good.</td>
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INTERVIEWER  | So, you don’t think it is an inquiry lesson. What are one or two changes that you would do to make it more inquiry? |
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<tbody>
<tr>
<td>Ava</td>
<td>So, they have the list of dominant traits. Maybe work off of that since they can already see who can roll their tongue they could make the activity a little more related towards that since they have something a little bit more concrete. You could ask them to make up their own way to figure out how a trait (mumbles to herself)...... Something where they can decide what they are testing where they are a little more influenced on it so that not everybody has the same. Different topic, different trait so just a little bit more options or more flexibility. The coins can be supplies and figure out a way to determine changes. Or give them another handout with more information to give them more of a backbone to work with so they will be able to work out an experiment on their own.</td>
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INTERVIEWER  | Anything else? |
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<tr>
<td>Ava</td>
<td>There is a part where they are asked if the ratios match up but maybe to have them do a little presentation or give them time for discussion to ask questions which they can revise.</td>
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INTERVIEWER  | The next task…I am going to give you a list of objectives. I am going to ask you to design a lesson based on these objectives. |
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<tr>
<td>Ava</td>
<td>There is a couple of different things. The first idea that popped into my head to talk about plants was epiphytes, the kind that just sit in the trees. So from that you are talking about plant structure, all plants have leaves, branches, and roots. So why are roots needed and why do epiphytes have roots if they are just floating in the tree. Discuss how plants get nutrients from roots so they need to be watered and as you know that most plants that sit in a dark room aren’t going to do to well either. The thing that is a little more relevant these days you can talk about converting light energy into chemical energy like a solar panel. That can be discussed. It is sort of a mechanical way that light energy can be converted into chemical energy. From there you can talk about chloroplasts and how they are little solar panels for a leaf and all of these can be combined into different experiments if you have them do investigations and make up investigations on plant growth. Keep it broad so that one could focus on sunlight, one on water, one on roots and soil. To factor in glucose as a source of energy as you are going along. I am trying to relate this to humans.</td>
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</table>
Kids are still going through growth spurts so what they need, a plant essentially needs as well and so then the... The carbon part is where people have difficulties with photosynthesis. That can be shown in an experiment but maybe could be more guided. It could be not a presentation but more guided inquiry. They should know that they are looking at carbon dioxide and that is the factor they are looking at since that is a more difficult concept. You could do this a bunch of ways but to keep it in line with plants you could get into a real quick carbon cycle could be talked about since they are an important factor in that since plants are an important part of that cycle. Do you want more specifics?

**INTERVIEWER** Well, where would you go from the cycle?

**Ava** From there, glucose could be tied into the carbon cycle so how glucose factors in with plants to help show the universality of carbon and why it is so important, it is the backbone of everything so it is an overarching goal. From there we can go into specifics of how carbon cycles into the plant cells.

**INTERVIEWER** Anything else?

**Ava** I think that is good for now.

**INTERVIEWER** The last task that I am going to do is show you three student models. So, essentially this is the question right here. All three students drew a model and we typed up their answers below. Take a minute to look at them and I will ask you some questions about them.

**Ava** Okay

**INTERVIEWER** If you notice there are numbers, so if you are talking about the models please refer to the numbers. What do you think is good about these models and try and be as specific as you can?

**Ava** The good thing about number one is they try and justify what they say (reads off of the model). They do label so you know what is going on in their drawings. For number 2, it is a little more detailed. You are starting to see it more at a cellular level. It is good labeling and the color coded of the different types of cells. Number 3 tries to justify their explanation (reads off of model). All of them are very well labeled and there are different levels of justification.

**INTERVIEWER** Okay, what do you think is problematic about them?

**Ava** For number 1, the question asks what happens to skin cells. They don’t really say. The mention the word scab but that doesn’t mean skin cells so they say the general process of how a scab forms but doesn’t relate to skin cells. For number 2 they talk about skin cells but they don’t do a justification (reads statement from model), who says that, no justification. For number 3, they do
well to show that it is the cells that are expanding to fill in the space and their justification is observation not empirical. It is just something they observed and is not backed by anything.

<table>
<thead>
<tr>
<th>INTERVIEWER</th>
<th>So, if these were their naïve models, what would you do in class the next day?</th>
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<tbody>
<tr>
<td>Ava</td>
<td>Everybody knows that a scab should cover a cut so maybe I would talk about how a scab forms so that they understand that the scab isn’t doing the healing, it is just a cover for it but there is stuff going on underneath the scab. They may need a refresher of how cells multiply and when and where they multiply.</td>
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<tr>
<th>INTERVIEWER</th>
<th>Okay, so what would you do in class the next day if these were the summative models? In other words, you already taught the material?</th>
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<tr>
<td>Ava</td>
<td>Maybe, I would try and you don’t necessarily want to put people's models on display unless they are used to it, but maybe have the models viewed by other students to point out the good things and bad things about the models because sometimes kids say things better to each other or it might just be directions weren’t clear and try and do a discussion. You could at least make sure that they have the information even if they couldn’t draw it so ask it in a different question or different situation to make sure concepts are transferable.</td>
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<tr>
<th>INTERVIEWER</th>
<th>Anything else?</th>
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<tbody>
<tr>
<td>Ava</td>
<td>You may just need to go over modeling again where they don’t know how in depth you wanted it.</td>
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<tr>
<th>INTERVIEWER</th>
<th>So you mean to give them a rubric of what you are looking for? What do you think would be a good model? In general.</th>
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<tbody>
<tr>
<td>Ava</td>
<td>A good model needs to answer the question, be well labeled, the justification if it is in a picture, the justification should follow along with the picture and relate to it and relate to things learned/read about to prove what you are saying is correct. This could be a little side thing where students have to address what the question is asking and then have them draw it, so more scaffolding.</td>
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Appendix F

Assignment Guidelines for the Lesson/Unit Design

Overall points:

- Make sure you use readable font and format
- Keep format consistent, clear and simple (you can use the header and footer to help with organization)
- Use headings and proper segmentation and add page numbers
- Provide all the materials necessary for enactment (or instructions on how to get them)
- Think with the users in mind, new teachers that may have never done inquiry and may not have extensive background knowledge in biology.
- In the teacher instructions refer to the teacher as “you” (second person not third). Don’t say - the teachers should do x; say “do x”

Sections:

Executive Summary: 120-200 words executive summary that is essentially a pitch for the unit, a brief description of what kids will be doing, what they will learn and why this unit is the best way to really learn this. Sell the unit to the teacher, it is important to make sure the teacher understands that it covers important state and national standards and the innovative nature of the instruction.

Curriculum Overview: 2-4 pages of an overview of the main goals for the unit (learning objectives) the project context and the macrostructures/nested structures. Give the reader a sense of what kids will be doing, what they will learn and how (the progression of lessons), and what big concepts are addressed by your unit. This is essentially your objectives, project context and backbone document (no more than 3 pages).

Standards: List the full titles of both state and national standards your unit addresses. If the unit addresses only part of a standard state that clearly. For national standards use either AAAS or NRC (you don’t need to use both unless you wan to).

Assessment Plan- 2 pages: a couple of paragraphs explaining embedded assessment, the system used in the unit (if you quote from the paper make sure to cite it appropriately). In a page or 2 explain the variables you chose and the elements and why they are important (again must include NOS, inquiry and content at least). Then, in a separate page (beyond the 2 pages), provide the assessment blueprint for the unit (a big excel table with all the variables and elements mapped onto lessons of the unit). Lastly provide one scoring guide for one non-content variable (NOS or inquiry).
**Notes:** Here go any additional notes or explanations about the unit that you feel need to be up front. For example if you plan a field trip you may wish to discuss it a bit here and make sure the teacher is aware of it and what prep work needs to be done. Or if your lesson plans use a format you wish to explain, this would be the place. Any other teaching philosophy points you think are important should be made here.

**Stages/Phases/Macrostructures:**

**Overview:** For each phase provide a title for that phase and a 1/2-page overview of the phase, in terms of goals, activities and assessments. Provide a sense of what will happen in each lesson and how they build on each other and hang together. You can list the lessons (give each a name) as bullet points. Make sure driving questions are made clear.

**Lessons:**

For each lesson give:

- A title
- Overview (one paragraph that connects this lesson to the next and pervious; gives the flow)
- Objectives- list them clearly, you can separate them out according to the relevant assessment variables (objectives for UC, objectives for Inquiry, objectives for NOS).
- Relevant student preconceptions- list and explain any relevant student conceptions (from your interview data) both in terms of conceptions that are problematic (need to be changed and may cause difficulties in understanding) and those that the teacher can build on (you can also refer back to these in the activities section).
- Standards for NJ- (for those specific objectives), if there are no relevant NJ standards provide national standards.
- Materials and preparation- include time, how long the lesson will take, a lesson can take several days.
- If you need to provide special instructions put that upfront before or after the materials section.
- Activities- this is the bulk of the lesson plan, its the instructions to the teacher (as numbered bullet points). You can also have special text boxes to covey certain types of information associated with the lesson (such as student conception box, alternative box, teacher tip box, etc)
- Differentiated instruction- what might you do to help students that are ELL or are lower achieving. Might include heterogeneous group organization or specific roles within groups. Use of multiple representations of data (written and graphical, or graph and table), etc.
- Assessment- these should appear in the lesson and in the blueprint, make clear which variables and elements are being assessed, not just what the assessment task is.
Supplementary materials—here, in an organized manner (with proper headings) provide any materials the teacher might need, be it handouts, reading material for students or the teacher, list of links to resources, whatever you think will help the teacher teach the lesson. Make sure that if you refer to a handout in the activities section that it appears (labeled in the same way) in this section.
Appendix G

Example Lesson

Christine, Teaching Experiment Lesson Plan, Methods II

**Student Prior Knowledge:** Students have already established the definition of an ecosystem. They have been introduced to the parts and ‘balances’ in an ecosystem. This lesson will focus on invasive species and how they disrupt an ecosystem. This lesson could be followed with a lesson on environmental policy, by endangered species, or by other examples of ecosystems that are impacted by invasive species.

**Goals:** Students should apply their knowledge of ecosystems to the problems that are created by invasive species.

**Objectives:**

Students will be able to describe the balances of an ecosystem and locate where the balance is disrupted when an invasive species is introduced.

Students will be able to anticipate the problems an invasive species will cause to an ecosystem by using examples to describe and support their ideas.

**Assessment:** Models, preliminary and post Worksheet

**Standards:**

**NJ Standards**

Standard 5.1: All Students Will Learn To Identify Systems Of Interacting Components And Understand How Their Interactions Combine To Produce The Overall Behavior Of The System.

5.2: All Students Will Develop Problem-Solving, Decision-Making And Inquiry Skills, Reflected By Formulating Usable Questions And Hypotheses, Planning Experiments, Conducting Systematic Observations, Interpreting And Analyzing Data, Drawing Conclusions, And Communicating Results.

5.12: All Students Will Develop An Understanding Of The Environment As A System Of Interdependent Components Affected By Human Activity And Natural Phenomena.

**National Standards**

6.6 Population Growth; Natural Resources; Environmental quality
**Lesson Development:**

**The Need-to-Know:** Right now the United States is being invaded by alien species. This invasion is devastating our forests and hurting many of our economic pursuits. Together we are going to explore the battle in Michigan between the Emerald Ash Borer Beetle and the ash trees. Ash trees are not only a native species but they are heavily cultivated for use in lumber and other wood products. Their alien attacker is the Emerald Ash Borer, native to China.

Separate the class into three groups and identify them as the tree experts, the bug experts and the predator experts. Give each of the groups background information on their topic and ask them to extract answers to specific questions onto index cards. The students will be given all necessary information to establish a working ecosystem in China and North America. The questions will be provided.

Establish Two Healthy Ecosystems: In a PowerPoint presentation have the groups fill in the blanks for a North American and Chinese ecosystem. Follow the model with slides about the effects of EAB infection in Ash trees. Challenge the class with the question of how this ‘worlds colliding’ situation can happen.

Invasion Explanation: Break the class into groups of three. Each group should have an ‘expert’ in each area of tree, bug, and predator. Distribute materials concerning the trade standards between the United States and China. Highlight the materials that could have been transferred in trade and export goods. Include packing wood crates, some imported wooden materials, and anything else the bug could have hitched a ride on.

In groups have students discuss ideas as to how the EAB got to the forests in North America.

Solve the Problem: Make a list on the board of possible solutions for this problem. While still in groups, ask students to have them hypothesize and model what they think the impact is with the new species in town and the impact of implementing one of the possible solutions.

Discuss their modeled solution as a class. What are the pro’s and con’s for each?

Example: import the mites that keep EAB in limited numbers in China.

- Discuss the impact that may have on native species
- Use the honeybee as an example as to the effect a dwindling population can have on the ecosystem as a whole.
Appendix H

Assignment Guidelines for the Final Reflection Paper

This is an individual paper about 4-5 pages long (space and a half)

It should address the following questions (please use bold questions as headings):

1. **How did my understanding of the nature of scientific inquiry develop this semester?**
   a. Think about what you have learned about inquiry through the various activities and assignments in class.
   b. Think about your initial philosophy paper- what changed in your understanding of how scientific knowledge develops through inquiry.

2. **How did my understanding of approaches to teaching science develop this semester?**
   a. What changed in your understanding of how we should be teaching science?
   b. How would you characterize a good science lesson? (be specific and give examples)

3. **What am I still unsure/confused about?**
   a. What is still difficult and/or confusing to you in regard to the topics covered in the first 2 questions?
   b. What else do you feel you need to learn to overcome the difficulties mentioned in (3a)?

The main goal of the reflection is to provide you with an opportunity to both reflect on the work and thinking you have done this semester, and to show me what you have learned. Don’t just tell me everything you know about the issues we discussed in class-- think about what you feel you learned. Keep this organized and thematic; don’t ramble. Be specific and give examples (explain any “buzz” words you use and don’t be vague). Use your journal and philosophy paper to think deeply about what you have learned and how your thinking has changed.

Make sure you use headings otherwise it’s hard to tell if you addressed all questions (you don’t need headings for sub-questions). Please label the file and subject line appropriately- “name final reflection” e.g. ravit final reflection.
Appendix I

Example Final Reflection Paper

Catherine, Methods II

1. How did my understanding of the nature of scientific inquiry develop this semester?

I finally understand scientific argumentation, how guided inquiry is important, and the importance of working in a group.

I never really understood what the difference was between discussion and scientific argumentation. I finally got it this semester though. I think it was a combination of the lessons we did as a class on cancer last year, readings, and having to develop the units. I learned that scientific argumentation means statements have to be backed up by evidence, whereas in a discussion or a debate, statements can be backed up by opinions and evidence, but evidence is not necessary.

Also, while reading through my reflection paper from last semester, I noticed I wrote about the importance of guided inquiry, but I don’t think I appreciated it until this semester. Through developing the lessons, I realized that a teacher cannot just run through the material without stopping and asking questions. I mean, she can, but the students will be lost and then they will stop paying attention. Plus, I learned that guided inquiry isn’t easy, that it may take some practice to learn what kind of questions to ask, to get students thinking in the right direction.

Also, this semester I learned the value of working in a scientific community and how that is important, through the intense group work that comes with developing our unit. At the beginning of the semester and even last semester, I didn’t agree with group work, I thought: I can get everything done easier and quicker by myself. You could say I had a snobbish attitude toward group work. But, not until the end of this semester did I realize that group work, while it can be grating, is also helpful. For example, if I need help with my part of an assignment, I have 4 other brains to come up with questions or help with ideas to get me going. Also, that means that if I wrote something that doesn’t make sense or needs to be revised, I have other people to critique my work, so we don’t hand an assignment in that is wrong. So, that is my selling point on group work, more brains are better than one. I will definitely have my students work in groups for things, so that they learn why working in a group (community) is beneficial to the quality of the ideas that arise from many people working together.

2. How did my understanding of approaches to teaching science develop this semester?

I think it’s important that students grasp the big ideas and not the small details. This is also how science works. I mean, the scientists have to go into the details about a concept, but that is just to help them understand the general concept better or to develop an understanding through using more evidence.
This semester, I learned how all of the parts of scientific inquiry go together in a class environment and a research environment. Currently, I am working in a research lab. Every day, I get to see how the grad students are working on their projects and relate it back to scientific inquiry. And I have learned from this that all parts of scientific inquiry are important and work together. In order to be a scientist, you must be well rounded. Look at all the things you have to do, come up with ideas, be able to argue effectively, work in groups, be modest when people criticize your ideas, but then again, these are skills that will help you get through most things in life. All the characteristics of scientific inquiry!

So with that, I think a good science lesson helps incorporate most of the science skills and helps the students understand the general ideas/concepts being taught, through detail, i.e. evidence. It’s important that students learn scientific inquiry, because it will help them understand science concepts better and, as mentioned above, will help them with skills they will need in whatever field they go into. In that case, a science lesson should have model development, argumentation amongst peers, revision, working with other class members, working with evidence, and interpreting ideas. Also, I mentioned that a good lesson helps students understand the general ideas/concepts being taught. For example, in our mitosis unit, while there are many details to learn about mitosis, like the names of specific phases, we just want the students to understand that mitosis is a process, it has steps, and chromosomes are involved in this process. Three of the main ideas of mitosis. Not, how much time it takes to go through each phase, or what other structures double in the cell during mitosis. We just want them to understand the big ideas! But, we use details, like the phases of mitosis and teach them about the cdk protein (regulation) to help them understand the big ideas.

3. What did I learn about the design of learning environments in science?

Through designing a science unit on mitosis and the lessons for that unit, the main thing I learned was how a unit needs to flow and the lessons need to follow logically. First, I would like to talk about how I learned how a unit should flow from lesson to lesson in a logical manner. This was a problem with my group’s unit. The ideas didn’t flow well, we kind of knee-jerked our way through developing lessons. Also, it ended up that our lessons weren’t following through with one another, i.e. they did not consistently use cancer and tumors to link to mitosis. We jumped around with those ideas. And if we left our unit like that, the students would be left wondering what cancer/tumors have anything to do with mitosis at all, and teaching the unit would have been a moot point. Also, I learned that the ideas presented in the lessons need to be reviewed and continued during the next lesson. If the lessons are connected to each other like this, the students are able to follow along with the unit. Then, as a teacher, I am able to help the students connect ideas, and therefore to learn.

In my observations, I learned that lab groups need to be managed, different student needs in the classroom need to be addressed, and that prior conceptions are important. Some people just don’t work well together. They fool around and waste time. I see that I might need to put together students of different knowledge levels, and maybe even different assessment levels into groups, when I
start working with students. That is why I think sometimes group members need to be hand-picked! Also, I observed a classroom with low level students and some IEP students, and I thought the class was very boring. When I talked to the teacher later though, it seems that these kids learn very well in a structured environment. And sometimes the kids with the IEPs learn well with different learning styles. So, they have visual, written, and verbal notes.

Also, I noted that prior conceptions are important when developing a lesson. Last semester, I wrote about how prior conceptions are important. But, I learned that from stuff we talked about in class and not experience. For my teaching lesson, I read an article about students’ preconceptions about what is an example of a vertebrate. And one of the things it said in the article was that high school students still become confused on whether a turtle and a snake are vertebrates, i.e. they think they aren’t. So I included pictures of them in my PowerPoint at the beginning of my lesson. And sure enough the kids got snake and turtle confused, i.e. some kids said they were vertebrates while others said they were invertebrates. My primary teacher asked them again at the end of the lesson what a turtle was classified as and what a snake was classified as. One of the kids said he knew a turtle was a vertebrate, because he had dissected one before. In the article, the authors mentioned that the students who knew that a snake and turtle were vertebrates, had had an outside experience with snakes and turtles before. Also, that all the rest of the students not involved in these type of nature experiences, need to be brought up to speed to the students that have had these experiences. When I heard the student say that in class, I thought that he was just like it said in the article! Knowing kids preconceptions can really help fuel the lesson!

4. **What am I still unsure/confused about?**

I am still unsure and confused about how to develop supplementary material, how to do differentiated instruction with inquiry, and distinguishing between different types of models. One of the problems I had with developing lessons for the unit, was developing supplementary material, especially when I was not super familiar with the material myself. I had trouble knowing what sort of readings to put together for kids to get them thinking the right ideas, and also not to give anything away. I know that technology helps, but I couldn’t find anything there I could use. I think part of my problem was that I wasn’t clear how much we wanted them to know about the concept of cell division regulation.

Also, I wonder how to do inquiry with differentiated instruction and with kids in IEP. If they need structured learning, inquiry is not really structured: How do we have these kids engage in inquiry? Same with the kids with different learning styles. How do we present inquiry to them? Do we have to come up with different types of learning materials? This is something I would like to know about.

I’m also still not quite there with understanding models. I understand how to write them into a lesson and why they are effective, but I still don’t think I absolutely understand them and am nervous about implementing them into a lesson and explaining them to kids. The reason why I am nervous, is because I am not 100% sure I would be telling them the right reasoning about the models, or that the students are even modeling what I want them to do.