Time Needed: Growth of Preservice Science Teachers' Knowledge of Inquiry and Practice of Lesson Design

Augusto Z. Macalalag Jr.
Arcadia University, 450 S. Easton Road, Glenside, PA 19038, macalalaga@arcadia.edu

Abstract: Recent reforms in science education require teachers to develop their notions of scientific inquiry and design effective inquiry-based lessons. This study examined the ways preservice teachers' knowledge of model-based inquiry (MBI) and their ability to use this knowledge in designing lessons developed over time. This study involved 15 preservice teachers enrolled in four consecutive methods courses in the biological certification program. Qualitative procedures were employed to analyze teaching philosophy papers and clinical interviews. Research findings provided evidence to support growth in preservice teachers' knowledge of MBI and its implementation in lesson designs: (a) from teacher-centered and activity-oriented to more student-centered lessons with modeling, and (b) from scripted to more sophisticated modeling practice. This 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 and lesson planning practices.

Introduction: The Use of MBI 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 (NRC, 2011). The pedagogical approach associated with teaching science as model building and testing is termed model-based inquiry or MBI (Cartier, Rudolph & Stewart, 2001). 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 (Windschitl & Thompson, 2006). MBI is 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, 2004).

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 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. "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 & 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 et al., 2001).

Theoretical Framework

Lesson planning is a ubiquitous practice for teachers and lesson plans are important artifacts of teaching. 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). Research studies have shown the different challenges that inservice and preservice teachers (PTs) 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.

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 (Justi & Gilbert, 2002). On the other hand, studies have shown that it was indeed possible for

 © ISLS

PTs to conceptualize and design student-centered lessons (Etkina, 2010; Fernandez, 2010). Teaching science through inquiry and developing inquiry lessons specifically around models and modeling is equally 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; Whindschitl & Thompson, 2006). In terms of the teachers' ability to design inquiry-based lessons, 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.

In summary, designing and implementing MBI instruction is challenging particularly for PTs. In the Methods courses of my study, PTs engaged in designing, revising, and implementing inquiry based lessons in four consecutive courses. The intensive focus on lesson design was part of Methods II and Methods III, which are described in the next section. 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 educational philosophy papers and clinical interviews 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? I anticipated that the PTs in my study would increase their attention to students' learning, curricula, and scientific models in their lesson plan and design over the four courses. More specifically, I hypothesized that the initial lesson designs would focus on the teaching models and didactic-approach similar to what Justi and Gilbert (2002) and Hayes (2002) found in their study. Given the findings from the studies by Etkina (2010) and Crawford (2004), I predicted that lessons would begin to focus on MBI with special attention to students' learning and development throughout the lesson. However, compared to the findings of Schwarz and Gwekwerere (2007), I hypothesized that the PTs in my study will consider a more sophisticated version of scientific models in their lesson design given time and emphasis in their methods courses.

Methods: Study Context

My study involved a 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 biological sciences (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.

As part of the certification program, the PTs completed four subject-specific methods courses in consecutive semesters (Methods I–IV). 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. In addition to the inquiry activities, in Methods I, PTs also engaged in lesson critique and revisions—an important aspect of teacher preparation (Duncan, Pilitsis, & Piegaro, 2010). 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 some design frameworks including Learning for Use (Edelson, 2001) and Backwards Design (Wiggins and McTighe, 2005). Lessons and activities in this course were scaffolded to increase PTs' repertoire in analyzing students' prior conceptions and alternative conceptions (Crawford, 2004), decision strategies involved in incorporating models and modeling in lesson design (Schwarz & Gwekwerere, 2007), incorporation of epistemological bases of scientific knowledge in lessons, 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.

Data Sources and Analysis

In order to capture changes in the 15 PTs' notions of MBI and its implementation on lesson design, I chose data sources that were relevant to issues of lesson design. The data included educational philosophy papers and clinical interviews, each of which is described below.

Semi-Structured Interviews. 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.

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. 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 (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 the "Findings" section of this document.

Clinical Interviews were conducted with each teacher at the end of each of the four methods courses. 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. This paper involved analyses of the third interview task in order to get a sense of PTs' knowledge of model-based inquiry and their ability to develop inquiry-based lessons, respectively. During the third task, PTs were asked to design a lesson based on three objectives given to them. 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.

Before conducting my analyses of the third task (designing a lesson), 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: (1) modeling (level 0—no modeling, level 1—script modeling, level 2A—modeling practice, and level 2B— argumentation) and (2) student-centeredness of lessons (level 0—teacher-centered, level 1—partly student-centered, and level 2—student-centered). 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. I describe and provide examples of each category and subcategory below.

Findings: PTs' Initial Ideas about Lesson Design

Research questions were addressed 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. The figure 1 below illustrates the salient themes that emerged from my analyses.

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. 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.

The components of lessons that PTs identified at this stage did not reflect MBI instruction in any way. Only two PTs mentioned the use of models and modeling as part of the lesson. 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)

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. 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.

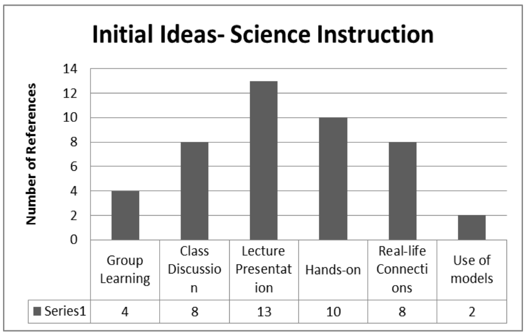

Figure 1. Science instruction based on the teaching philosophy papers.

Model-Based Inquiry

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... 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... 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)

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)

The majority of lessons did not include argumentation. They did not use evidence to inform their discourse around models. 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 1 shows changes in modeling as part of lessons in clinical interviews.

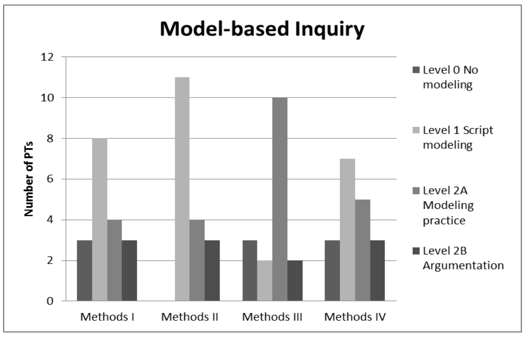

Figure 2. MBI based on clinical interviews.

Designing Student-Centered Lessons

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.

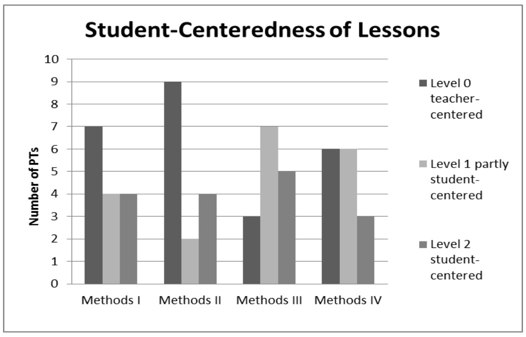

Figure 3. Student-centeredness of lessons based on clinical interviews

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, CO_2, probes to get CO_2. I will ask them to do an experiment of some kind that will show the changing of concentrations of O_2 and CO_2 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, the teacher provided the experiments and connections for his/her students. On the other hand, half of the lessons developed in Methods III were student-centered lessons (level 2). 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. 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. Molly described how she would demonstrate an experiment, ask her students to design and conduct their own experiments, and end the lesson by re-visiting 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)

Discussion and Implications

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), design MBI lessons (Schwarz & Gwekwerere, 2007), and attend to student thinking (Hayes, 2002).

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. 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. 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. 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.

Contrary to the PTs in the studies of Schwarz and Gwekwerere (2007), 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. 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. However, 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.

PTs encountered difficulty in embedding argumentation as part of scientific practice. 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. 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.

Teacher-educators can better prepare pre-service 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. 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.

References

Cartier, J., Rudolph, J., & Stewart, J. (2001). *The Nature and Structure of Scientific Models*. The National Center for Improving Student Learning and Achievement in Mathematics and Science. Retrieved on December 4, 2010 from http://ncisla.wceruw.org/publications/reports/Models.pdf

Crawford, Barbara (2004). Supporting prospective teachers' conceptions of modeling in science. *International Journal of Science Education, 26*(11), 1379–1401.

Duncan, R.G., Pilitsis, V., & Piegaro, M. (2010). Development of Preservice Teachers' Ability to Critique and Adapt Inquiry-based Instructional Materials. *Journal of Science Teacher Education, 21,* 81-102.

Duschl, R.A., Schweingruber, H., & Shouse, A. (Eds.) (2007). *Taking Science to School: Learning and teaching Science in grades K-8.* Washington DC: The National Academy Press.

Duschl, R.A. & Wright, E. (1989). A case study of high school teachers' decision making models for planning and teaching science. *Journal of Research in Science Teaching, 26*, 467-501.

Edelson, Daniel. (2001). Learning-for-Use: A Framework for the Design of Technology-Supported Inquiry Activities. *Journal of Research in Science Teaching, 38*(3), 355-385.

Etkina, Eugenia. (2010). Pedagogical content knowledge and preparation of high school physics teachers. *Physics Education Research, 6,* 1-25.

Fernandez, Maria Lorelei. (2010). Investigating how and what prospective teachers learn through microteaching lesson study. *Teaching and Teacher Education, 26*, 351-362.

Friedrichsen, P.J., Abell, S.K., Pareja, E.M, Brown, P.L, Lankford, D.M., & Volkmann, M.J. (2009). Does Teaching Experience Matter? Examining Biology Teachers' Prior Knowledge for Teaching in an Alternative Certification Program. *Journal of Research in Science Teaching, 46*(4), 357-383.

Gilbert, J. & Boulter, C. (1998). Learning science through models and modelling. In Fraser, B. and Tobin, K. (Eds.), *International Handbook of Science Education (pp. 53-66).* Dordrecht, The Netherlands: Kluwer Academic.

Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education,* 22(9), 1011-1026.

Hayes, Michael. (2002). Elementary Preservice Teachers' Struggles to Define Inquiry-based Science Teaching. *Journal of Science Teacher Education, 13*(2), 147-165.

Justi, R. & Gilbert, J. (2002). Science teachers' knowledge about and attitudes towards the use of models and modeling in learning science. *International Journal of Science Education, 24(*12), 1273–1292.

Kazemi, E. & Franke, M.L. (2004). Teacher Learning in Mathematics: Using Student Work to Promote Collective Inquiry. *Journal of Mathematics Teacher Education, 7,* 203-235.

Merriam, S. B. (1988). *Case Study Research in Education: A Qualitative Approach.* SF, CA: Jossey-Bass.

National Research Council. (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: National Academy Press.

Schwarz, C.V. & Gwekwerere, Y. (2007). Using a Guided Inquiry and Modeling Instructional Framework (EIMA) to Support Preservice K-8 Science Teaching. *Science Education, 91,*158 – 186.

Shavelson, R. J. (1987). Planning. In Dunkin, M. (ed). *The International Encyclopedia of Teaching and Teacher Education (pp. 483-486)*. Oxford, England: Pergamon.

Wiggins, G. & McTighe, J. (2005). *Understanding by Design (2nd ed.).* Alexandria, VA: Association for Supervision and Curriculum Development.

Windschitl, Mark (2004). Folk Theories of ''Inquiry:'' How Preservice Teachers Reproduce the Discourse and Practices of an Atheoretical Scientific Method. *Journal of Research in Science Teaching, 41*(5), 481–512.

Windschitl, M. & Thompson, J. (2006). Transcending Simple Forms of School Science Investigation: The Impact of Preservice Instruction on Teachers' Understandings of Model-Based Inquiry. *American Educational Research Journal, 43*(4), 783-835.

Windschitl, M., Thompson, J., & Braaten, M. (2008). How Novice Teachers Appropriate Epistemic Discourses Around Model-Based Inquiry for Use in Classrooms. *Cognition and Instruction, 26,* 310-378.

Acknowledgments

I owe tremendous gratitude to Dr. Ravit Golan-Duncan for guiding me in conceptualizing and framing this research study. I also would like to thank Moraima Castro, Vicky Pilitsis, John Ruppert and Dr. Nicole Shea for their recommendations and insights on my literature review and analysis of data.

 © ISLS