

THE DEVELOPMENT OF PROSPECTIVE SCIENCE TEACHERS' KNOWLEDGE OF
MODELING AND MODELING-ORIENTED ASSESSMENT DURING TEACHER
EDUCATION

by

YOUNG AE KIM

(Under the Direction of J. Steve Oliver and Deborah Tippins)

ABSTRACT

Teaching science using models and modeling is a fundamental part of science education worldwide. Modeling is one of the core practices in the NGSS. This study examined secondary preservice science teachers' learning and enactment of instructional practices related to modeling. As presented in this dissertation, the study has three major parts. In part I, a literature review examines linkages between Modeling-Oriented Assessment and Authentic Assessment with regards to its implications for prospective science teacher education. It is highlighted that MOA has essential characteristics of authentic assessment. This component of the study builds relationships between these conceptual domains in a novel way in order to provide new understanding for the use of modeling in science teacher education. In part II, research is reported in which prospective science teachers learned about and then implemented lessons focused on modeling. By teaching modeling activities to elementary science prospective teachers, the secondary prospective teachers exhibited behaviors that are consistent with pedagogical content knowledge (PCK). In addition, the prospective teachers recognized that modeling is an effective instructional strategy and has benefits for students related to the diverse forms of modeling. In part III of the study, research is reported on the adaptation of knowledge

about Modeling-Oriented Assessment by prospective science teachers into rubrics that are planned for use with future students. Data analysis showed that the prospective teachers also added new categories that were not originally included in research related to MOA. The prospective teachers were not able to see benefit in the assessment of meta-modeling knowledge of future students. In addition, the prospective science teachers created ‘filters’ such as fairness related to grading that were powerful influences on the final form of the created rubric. This dissertation showed the importance of experiences with modeling and opportunities for implementation of modeling in teacher education. By introducing MOA and authentic assessment into prospective teacher preparation courses, the knowledge of modeling can be enhanced with a comprehensive view of modeling. In addition, the study identified needs to support prospective teachers’ learning about assessment itself and meta-modeling knowledge in teacher education.

INDEX WORDS: model, modeling, assessment, prospective science teacher, pre-service teacher, modeling-oriented assessment, model-based assessment, science teacher education

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DEDICATION

I dedicate my dissertation work to my Lord, Christ Jesus. I also dedicate this work to my family and many friends. I would like to express a special feeling of gratitude to my loving parents, my dedicated husband, and lovely son and daughter, Eunwoo & Eunyul.

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CHAPTER 1

INTRODUCTION

Modeling practice is one of the core practices in the *Next Generation Science Standards* (NGSS) and can be an active learning approach which offers students the chance to describe, explain, and predict scientific ideas (NRC, 2012). As such, modeling practice is one additional form of subject matter content representation available to teachers in science instruction. The use of multiple representations means that science content is represented in a variety of forms (e.g., text, figures, drawings, diagrams, physical models, mathematical equations, computer simulations, etc.). Modeling in science classrooms has been demonstrated to be an effective instructional strategy as well as an assessment tool within the teaching of scientific concepts/content as well as scientific practices. Further, modeling practice has been shown to be a means to support inquiry in the science classroom, such that students construct their own models and revise models in response to new evidence and information just as scientists do (Windschilt et al., 2008).

In this respect, student ownership needs to be emphasized in modeling activities as a component of active learning (NRC, 2012; Quellmalz et al., 2012). However, in many cases, research has shown that teachers use models and modeling activities for demonstrating and explaining scientific phenomena, often in activities carried out by teachers with the students observing in a passive way. So, recognizing the importance of promoting teachers' knowledge development on models/modeling as an active learning approach is significant in teacher education. The research reported in this document is an effort to promote and study the

development of this type of active learning instruction using modeling among a group of secondary science prospective teachers.

Rationale for the Study

Models and modeling have been used in science learning for many years. The effectiveness of modeling in science teaching and learning has been evident in many context including studies of active, inquiry-based, student-centered, collaborative learning, and use of multiple representations for diverse learners (Krajcik & Merritt, 2012; NRC, 2012; Quellmalz et al. 2012). Scholars have studied a variety of different approaches to modeling with different forms and have highlighted different aspects of models and modeling.

With the emphasis on modeling in the NGSS, the importance of effective strategies for modeling practice has drawn increased attention. At the same time, the promotion of modeling practice calls for approaches to assess students' models and modeling in alignment with modeling curriculum. In science teachers' everyday practices in their classrooms, learning through modeling can take many forms. Students can be encouraged to question why the phenomena looks as it does, what happens in the phenomena, and what reasoning is required for visualization of their ideas of the phenomena. It is important for teachers to know how to promote students' better understanding and learning practices in science learning through modeling. English (2008) addressed the ways in which modelling promotes students' understanding of a wide range of key mathematical and scientific concepts and concluded that it is a powerful way of learning mathematics and science.

Schwarz and White (2005) advocated for students' learning about a particular form of knowledge related to models and modeling, termed as *meta-modeling knowledge*. Meta-modeling knowledge can be described as the accessible self-knowledge that a learner has

available to aid his/her own model construction and evaluation. One assumption, according to these authors, is that meta-modeling knowledge guides modeling process and influences the quality of models. However, this research also suggests that, in the process of modeling, sometimes students are just jumping in without guidance of any knowledge about the nature of models and modeling. Thus, there are needs, especially within teacher education, to closely look at the relationship between meta-modeling knowledge and the modeling construction process in relation to the interaction of teachers and students in science classrooms. To give valuable feedback to students' learning through and about modeling practice, we need to make prospective teachers better prepared for implementing modeling in their instruction (Namdar & Shen, 2015) by learning meta-modeling knowledge and its relationship with model quality and modeling process.

A variety of scholars and teacher educators have studied prospective teachers' knowledge of models and modeling (Crawford & Cullin, 2004; Daunsso et al., 2010; Frede, 2008; Kim, 2015; Kenyon et al., 2011; Nelson & Davis, 2012; Ogan-Bekiroglu, 2006; Schwarz, 2009; Windschitl & Thompson, 2006). One common finding from among these studies is that many prospective teachers are confused in terms of their understanding of models and other highly related constructs such as scientific method, demonstration, experiment, theories, or inquiry (Danusso et al., 2010; Kenyon et al., 2011; Schwartz, 2009; Windschitl & Thompson, 2006; Windschitl et al., 2008). Prospective teachers also are noted to have struggled with incorporating model evaluation, revision, and meta-modeling in their lessons (Schwartz, 2009). If prospective teachers understand modeling as a scientific practice similar to what scientists do, but they do not incorporate knowledge of models and modeling into their science teaching with students, it is problematic. And from this, it follows that prospective teachers would not be willing to use

modeling or teach about modeling in their science classrooms (Crawford & Cullin, 2004).

Research suggests that prospective teachers' limited knowledge of modeling is at the heart of this issue.

When we think about the alignment with curriculum, instruction, and assessment, preparation of teachers for instruction using modeling is significant. In many cases, modeling practices are just done as instructional activities in instruction but not assessed. As Schwartz (2009) indicated regarding the difficulty of prospective teachers' integration of model evaluation in science teaching, there needs to be support to promote their understanding of how to assess models, modeling, and meta-modeling knowledge of students, criteria to be used in those assessments, as well as the forms of assessments that can be used in their teaching. Further, the research reported here will develop the idea of how Modeling-Oriented Assessment (MOA) can be a form of authentic assessment in terms of the integration of instruction and assessment, and reflection of professional life (e.i. scientists' practices).

Structure of the Dissertation

This dissertation consists of three sub-units. Each sub-unit will be presented here as a stand-alone manuscript.

a. A Review of Literature: MOA & Authentic Assessment

The first sub-unit (Chapter 2) is a review of the literature on Modeling-Oriented Assessment (MOA) and its link to authentic assessment of learning in the science classroom. In the part 1 of chapter 2, we review how authentic assessment has been conducted in K-12 science education and the essential characteristics of authentic assessment in K-12 science education. Then, the MOAA (Modeling-Oriented Authentic Assessment) framework will be presented as means to link the characteristics of MOA to the research literature on authentic assessment. Part

II of chapter 2 includes a review of research related to prospective teachers' understanding of models and modeling in the context of prospective science teacher preparation. Finally, the implications of preparing prospective science teachers to implement modeling instruction and modeling-oriented assessment (MOA) are combined with the scholarship on authentic assessment to finalize the MOAA model as a tool in science teacher education.

b. Research paper 1 (Chapter 3):

Prospective Teachers' Development of Knowledge of Modeling as an Instructional Strategy through its Implementation in the Context of Peer Teaching

In the second unit (Chapter 3), we examine secondary prospective teachers' understanding of models/modeling in the context of a learning experience with models/modeling during a science methods course. In addition, we examine their implementation of model-based instruction as a form of mini-lesson in the context of peer teaching. The manuscript maps out the sequence of events in which the prospective teachers participated and presents the analysis of data collected at points along this sequence. The prospective teachers had learning experiences about model-based instruction, followed by opportunities to implement modeling mini-lessons to prospective elementary teachers in another science methods course. The implementation of mini-lessons with unfamiliar learners (prospective elementary teachers) required the secondary prospective teachers to put considerable effort into preparing and introducing model-based instruction to the elementary prospective teachers. The analysis examines how the participants demonstrated their understanding of model-based instruction. In this paper, three representative cases are introduced. The implications of prospective teachers' learning about models/modeling and model-based instruction are described.

c. Research paper 2 (Chapter 4):

Prospective teachers' understanding of MOA (modeling-oriented assessment) in science classrooms.

In the third unit (Chapter 4), we investigate secondary prospective teachers' understanding of assessment of models/modeling through the experience of creating a rubric using MOA in the secondary science methods course. The prospective teachers were introduced to Namdar & Shen (2015)'s MOA framework in order to help them understand assessment of models/modeling comprehensively. The prospective teachers also participated in a discussion of possible evaluation criteria and explored the evaluation of models with examples of student-generated models. Then, they had an opportunity to create a rubric to assess models, modeling, or meta-modeling knowledge, referring to MOA framework. Semi-structured interviews were followed by experience in creating a rubric using MOA. Data source were assessment rubrics, participants' written reflection on the rubrics, and interviews. Most MOA criteria were generated in the dimension of assessment of models by the participants. The analysis showed that there were few attempts made to assess meta-modeling knowledge of students by the participants. From the analysis, we also constructed filters to describe the factors that influenced the prospective teachers' decision-making when creating the MOA rubrics. The implications of prospective teachers' understanding of assessment of models/modeling in K-12 science classrooms is also discussed in this paper.

Research Questions

In this dissertation, the overall research question is, '*how do prospective teachers develop knowledge of models/modeling and its assessment in science method course?*' To answer this overall research question, we have sub-questions in each sub-unit.

a. Research questions for chapter 2

- What is prospective teachers' understanding of models/modeling?
- What are prospective teachers' challenges and successes in learning models/modeling?
- What is the relationship between MOA and authentic assessment in K-12 science education?
- What are the implications of prospective teachers' understanding of MOA as authentic assessment in teacher preparation?

b. Research questions for chapter 3

- What instructional knowledge do prospective secondary science teachers develop while designing and implementing modeling instruction during their methods and practicum coursework?
- What characteristics of pedagogical content knowledge on modeling (PCKm) as an instructional strategy do prospective secondary science teachers demonstrate?

c. Research questions for chapter 4

- How do prospective secondary teachers (PSTs) develop understandings of MOA (Modeling-Oriented Assessment) as evidenced by the design of assessment rubrics?
- What successes and challenges do PSTs experience when engaging in the design of assessment rubrics using MOA?

Research design

a. A review of literature in Chapter 2

In this literature review, we completed two different but related reviews. These reviews are labeled as part I and part II. The two parts are brought together and synthesized with regards to its implications for preservice science teacher education. In part I, we reviewed research

literature on MOA and authentic assessment, and the relationship between the two constructs. In part II, we reviewed studies of prospective teachers' understanding of models and modeling in science education. This was followed by a discussion of the implications for teacher preparation with respect to model-based instruction and assessment, and informed by both sections of the review.

In part I, we reviewed authentic assessment in K-12 science education. We searched mostly using the electronic database ERIC. We selected peer-reviewed, science-related subjects, and empirical research based articles. A few articles were included from practitioner's journals when those articles were based on empirical experiences in science classrooms and had important implications (e.i. Bouwma-Gearhart & Bouwma, 2015; Doran et al., 1992) for the understanding of the two related parts of the synthesis. This literature search spanned studies from 1980 until 2016. Most of the literature on authentic assessment has emerged since the 1990s. After the articles were assembled in our collection, we coded the individual articles based on a coding schema that included study information (e.g. author, year, assessment task format, criteria, etc) as well as findings from the research.

For Part II, similar to the review of relevant literature in Part I, we used ERIC search as a main source. We searched the most recent two decades (from 1998 to 2016) for research on PSTs' understanding of science teaching with the modeling for future students. We included only peer-reviewed, empirical research articles, published in English and related to science content. After the articles were assembled in our collection, we coded the individual articles based on a coding schema that included study information such as author, year, research interest, research design, findings, etc. Then, we generated themes based on the analysis.

b. Research design for chapter 3: *Prospective science teachers' understanding of modeling through implementation of modeling*

At the beginning of semester, we conducted an open-ended survey on modeling as part of an effort to understand the prospective teachers' prior knowledge of modeling. The primary purpose of this survey was to guide participant selection from among the volunteers in the course. Sampling technique was selection with maximum variances based on major, gender, lab experience, MAT/BSES among volunteers. During the semester, three semi-structured interviews were conducted with five primary participants. The first interview was focused on the prospective teachers' general ideas about modeling. The second interview was mostly focused on the prospective teachers' understanding of MOA. The third interview was focused on the prospective teachers' experience with modeling mini-lessons. The first and second interview transcripts served as main data source for chapter 4, and the first and third interview transcripts served as the main data source for chapter 3. However, all three interviews contributed to the development of both papers (chapter 3 and 4) for triangulation.

We utilized a qualitative case study research design. The research participants were secondary science prospective teachers who were taking a secondary science methods course as part of their science education degree and certification program. In this paper, our goal was to examine the prospective secondary teacher participants' knowledge about modeling and their enactment of this knowledge in lesson designs and implementations in a similar context of teaching learners who are new to modeling practice. Semi-structured interviews, video-recordings of mini-lessons, class discussions, and lesson plans are data sources. Data analysis was conducted using grounded theory, then we used constant comparative analysis technique

(Charmaz, 2000; Glaser & Strauss, 1967) in light of the Park & Oliver (2008)'s PCK model.

Three representative cases were described in detail in this manuscript.

- c. Research design for chapter 4: *Prospective teachers' understanding of MOA (modeling-oriented assessment) in science classrooms.*

The research context and participants of this study were the same as discussed in chapter 3. In this study, the participants were introduced to the Modeling Oriented Assessment (MOA) framework after participating in modeling activities in the science methods course. After the MOA introduction, each of the primary participants construct their own individual rubric using modeling as a part of their unit plans. When the prospective teachers submitted a rubric, they also wrote a reflection on the rubric they created. The semi-structured interviews were conducted before and after the experience of creating the MOA rubric. The data sources were the modeling-oriented assessment rubric, prospective teachers' reflection on the rubric, and semi-structured interviews. The data analysis was done using theoretical thematic analysis (Braun & Clarke, 2006). Five cases were described followed by a cross-case analysis in this paper.

In Chapter 5, we look at the overview of findings from chapter 2, 3, and 4. Then, we discuss the significance of the findings in terms of the whole study. Finally, we discuss the implications of this study for science teacher preparation.

CHAPTER 2

MODELING-ORIENTED ASSESSMENT AS AN AUTHENTIC ASSESSMENT: A THEORETICAL FRAMEWORK IN SCIENCE EDUCATION¹

¹ Kim, Y. and Oliver, J. S. To be submitted to *Teaching and Teacher Education*.

Abstract

This synthesis of the research literature establishes connections between the scholarship on modeling-oriented assessment, authentic assessment and pre-service science teacher education. Recommendations for the preparation of science teachers in keeping with the directives of the NGSS are drawn from the interconnections of these three distinct areas of scholarship.

Introduction

In recent reform movements and policy initiatives, modeling is highly emphasized as a scientific and engineering practice which students should learn from an early age (NGSS Lead State, 2013; NGSS, 2012). From modeling practice, students are able to be engaged in a form of scientific practice with ownership. According to Windschitl et al. (2008), modeling fosters active learning by representing scientific ideas through model creation and revision. Modeling is an essential practice needed to describe and explain the scientific aspects of natural processes. These actions, to describe, explain, and predict, commonly happen in science classrooms. In many cases, teachers try to explain already established science by demonstrating models. However, if students are given opportunities to actively participate in a comprehensive range of modeling practices, then their opportunities to learn science across a variety of scientific contexts is enhanced. Krajcik and Merritt (2012) stated that modeling practice will bring big change in science learning in that by constructing and revising models, students will be engaged in scientific thinking.

In K-12 science and engineering education, students develop foundational knowledge and skills continuously over multiple years (NRC, 2012). To build students' knowledge and abilities in science and engineering, the *Next Generation Science Standards* recommended three-

dimensional science teaching that includes: Disciplinary Core Ideas, Scientific and Engineering Practices, and Cross-Cutting Concepts. To support students' meaningful learning in science, these three dimensions need to be dealt with in an integrated way (NRC, 2012). In the spirit of NGSS, modeling practice also needs to be approached in terms of the integration of core ideas and cross-cutting concepts. Bouwma-Gearhart & Bouwma (2015) argue that modeling promotes a deep understanding of scientific phenomena through participation in genuine scientific practices. These authors also explained that students actively engage and collaborate in data analysis toward the development, revision, use, and presentation of models like scientists.

There have been pedagogical debates surrounding scientific practices and direct instruction in science learning (NRC, 2007). The authors described the debate in this way,

First, some pedagogical debates rest on differences in values rather than questions that are answerable through empirical research and, accordingly, cannot be resolved in this chapter. For example, one may be tempted to ask “Is inquiry better than direct instruction?” However, when comparing inquiry and direct instruction, the critical question is “Better for what?” Advocates of one or the other instructional approach may have different underlying visions for what it means to learn science. Thus, we need to be clear about what our goals for science learning are and ask how inquiry and direct instruction compare in reaching specific educational goals. (NRC, 2007, p. 252).

As stated, there is no right answer in the debate over science as practice and direct instruction of science content. However, direct instruction without the practice of science has been the norm in science classrooms (NRC, 2007). Modeling as a scientific practice has been emphasized in science learning and is reflected in NGSS. In the body of literature related to modeling research, there is also debate over teaching with more emphasis on modeling practice

in contrast to emphasis on content knowledge. But, this contrast raises the question of how students can do modeling without learning science content in science classrooms?

In this paper, we view modeling as a knowledge-building tool (Schwarz et al., 2009) through which students learn both scientific practices and science concepts/content. Our integrated view of the purpose of modeling is that it is a useful instructional technique for finding balance between learning practices and content. In particular, we are in agreement with Manz (2012) who clearly asserted the importance of the ‘co-development’ of practice and conceptual understandings through modeling.

Given the importance of modeling, how can we implement and evaluate modeling practice in science teaching? How can we give feedback to students on their own modeling to improve their practice? And, how can students get ideas about what a good model is and how to do modeling? In curriculum, if modeling is one of the core practices that needs to be taught, students also need to learn and have ideas about models and modeling. This chapter will examine these questions from the perspective of the science education research literature.

When we think about experience of models during classroom experiences, we can easily come up with the idea of constructing a cell model as a representative student project or an assignment including the creation of plant and animal cell models with clay, and labeling cell organelles. However, educational experiences like this are often students’ only experience in school related to models and modeling. And these experiences are often the only experiences that students have with models of their own construction being graded. In this case, model evaluation can be perceived of as a type of alternative assessment to traditional paper-pencil tests. These assumptions raise two questions that are at the heart of this work. First, how can science teachers assess models and modeling of students? Second, how do teachers learn about the assessment of

models and modeling? The research on teachers' knowledge on modeling and assessment give many important implications to foundational work related to models and assessment in teacher preparation.

Namdar & Shen (2015) introduced a framework of Modeling-Oriented Assessment (MOA) for K-12 science education. The authors examined and synthesized how the assessment of students' knowledge, skills, and practices directly related to models and modeling. Modeling-oriented assessment (MOA) has been represented in the research literature (i.e., they identified 30 articles) for roughly the past three decades (from 1980 to 2013). Namdar & Shen (2015) suggested that thinking about assessment of models and modeling, modeling-oriented assessment (MOA) should start with the consideration of the alignment with curriculum, instruction, and assessment. Their synthesis study of MOA (Namdar & Shen, 2015) examined research articles of how researchers investigated the use of modeling, and modeling assessment. However, their MOA study was not about how teachers have used MOA for assessment in their classrooms. If modeling is emphasized in K-12 instruction in relation to the NGSS, then assessment of modeling also deserves some attention. Namdar & Shen's (2015) study implied the possibility of MOA as an authentic assessment which is aligned in ways similar to professionals' practice (e.g. scientists) and the alignment with instruction and assessment in educational settings. Even though there are a lot of possibilities for authentic assessment and benefits to MOA, if teachers are not willing to use MOA as a realistic classroom assessment practice, modeling cannot be understood by students. In our current study of prospective teachers' understanding of MOA, participants also hesitated to use MOA as an assessment tool and discussed the difficulties in implementing MOA such as fairness, grading, and the challenges of designing appropriate tasks,

etc. In this sense, the hesitation may be due to the complexity of modeling as well as the difficulty of implementation of MOA in practical classroom settings.

In this paper, which builds upon Namdar & Shen's (2015) synthesis study of MOA, we discuss how MOA would align with the characteristics of authentic assessment. First, we examine how authentic assessment has been conceptualized in science education at K-12 levels. Second, we suggest a new model (Modeling Oriented Authentic Assessment: MOAA) based on MOA (Namdar & Shen, 2015) and the authentic assessment model of Gulikers et al. (2004). Finally, we discuss prospective teachers' understanding of assessment of models and modeling as reflected in the literature. This review of literature on MOA, authentic assessment, and teachers' knowledge of modeling assessment will inform ways to support teachers to understand modeling and its assessment. The practicality and authenticity of MOA needs to be understood and promoted in a meaningful way in science teacher education.

In the next section, we will discuss authentic assessment and how it has been studied in K-12 science education. Before examining authentic assessment in K-12 science education, we will discuss the characteristics of authentic assessment in education in general.

PART I: Authentic Assessment in K-12 Science Education

Methods

Literature Collection and Coding

With these goals in mind, the literature review was conducted using the electronic database ERIC, as well as the specific science education journals (e.g., Science Education). The search generated a huge number of references and the following criteria were used to include or exclude relevant literature in the collection. First, the selected articles are peer-reviewed research

articles. Commentaries or articles published in practitioners' journals were generally excluded. However, among the articles published in practitioners' journals, two articles were directly related to modeling and informed assessment tasks for authentic assessment with modeling, so I included them in the collection. They are: Bouwma-Gearhart & Bouwma, (2015); Doran et al., (1992). These two articles are based on their empirical experiences in science classroom although not research articles. Finally, articles chosen had to be science-related in terms of subject.

Consistent with MOA (Namdar & Shen, 2015), this literature search spanned studies from 1980 until 2016. Namdar & Shen's (2015) MOA search was from 1980 to 2013, but the search for authentic assessment manuscripts in this review was to include 2016. Most of the literature on authentic assessment has emerged since the 1990s. Only studies published in English from 1980 to 2016 were included.

In terms of assessing teachers' practice in using authentic assessment, studies needed to be related to science teaching, not just general teaching practice or literacy. Also excluded were papers only focusing on assessment of learning without any description of an authentic assessment perspective.

Finally, I did not search 'performance assessment' or 'alternative assessment' even though oftentimes those terms are used interchangeably with authentic assessment; instead I examined studies using only the term 'authentic assessment' within their definitions. Various combinations of the following keywords were used in the search:

(Keywords:"authentic assessment") and (Keywords:"science education"),

(Keywords: "authentic assessment") and (Keywords: "science")

(Keywords:"authentic assessment") and (Keywords: "modeling"),

(Keywords: "authentic assessment") and (Keywords: "science") and (Keywords: "model"),

and (Keywords: "authentic assessment") and (Keywords: "science education") and (Keywords: "model").

Based on the above criteria, I selected 9 articles among 45 articles from the initial search. In this search, the main focus was on the types of authentic assessment tasks have been done in K-12 science education. When I searched using just “authentic” or “authentic learning”, there were a huge number of articles, but by limiting the search to “authentic assessment” which is the interest of this paper, the number of articles was reduced to 45 articles.

After the articles were selected, I coded the individual articles based on a coding schema that included study information (e.g. author, year, title, source (including e-copy URL), article type, goals of assessment (outcome variables), assessment task format, criteria, sample size, social context in instruction, social context in assessment, subject, and research design. However, the focus was goals of assessment, assessment task formats, social context in assessment, and criteria among coding schema based on Gulikers et al. (2004).

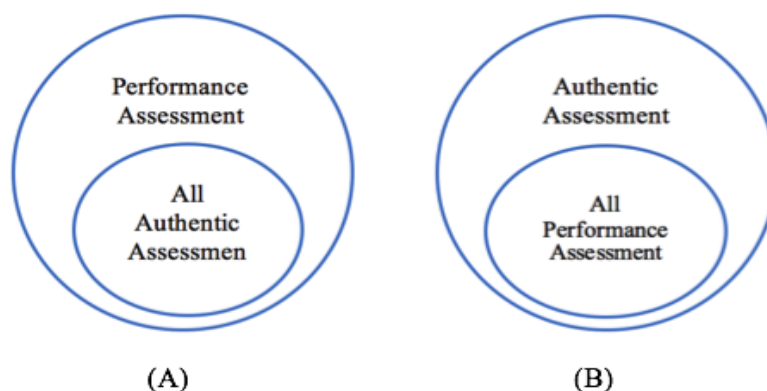
Prior to examining the research that is specifically related to K-12 science education and authentic assessment, there will be an examination of the meaning of authentic assessment and related terms in order to establish where authentic assessment fits within the larger picture of assessment in formal educational settings.

Literature Synthesis

Emergence of Authentic Assessment in Education

The discussion of authentic assessment begins with criticism of standardized testing (Archbald and Newman, 1988; Frey et al., 2012). Since the 1990s, with the re-emergence of assessment instead of standardized testing, many scholars have suggested different terms such as performance assessment, alternative assessment, and authentic assessment, to describe assessments of learning that are matched to the manner in which the student learned or demonstrated learning through action. In many cases, the terms have been used interchangeably. However, the common features of these constructs are that they are considered as alternatives to traditional standardized tests and referred to direct examination of student performance in realistic tasks (Worthen, 1993a).

To clarify the meaning of authentic assessment, performance assessment, and alternative assessment, Oloruntegbe (2010) distinguished among these three constructs in the following manner. According to Oloruntegbe (2010), authentic assessment is “a form of assessment in which students are asked to perform real-world tasks that demonstrate meaningful application of essential knowledge and skills.” (p. 14). In contrast, performance assessment is “a form of testing that requires students to perform a task rather than select an answer from a ready-made list (p. 14)” and includes open-ended response items, portfolios, teacher observation of student activities, products, essays, and oral presentations. The third term, alternative assessment, includes any assessment in which students create a response in any alternative form such as short answer, essay, musical recitals, theme papers, drama performance, and models that differs from traditional assessment.



(A) Oosterhof (2003), Mertler (2003), Popham (2002)

(B) Kubiszyn & Borich (2003), Talyor & Bobbit-Nolen (2005)

Figure 2.1 Possible conceptual relationship between performance and authentic assessment. (from Frey, Schmitt, & Allen, 2012, p. 3)

Frey, Schmitt, & Allen (2012) addressed two opposing possible conceptual relationships between performance and authentic assessment as reflected in research literature (*Figure 2.1* from Frey, Schmitt, & Allen, 2012, p. 3). In part A, all authentic assessments are considered to be examples of performance assessments, while in part B the opposite is true. Part B of this diagram is more conceptually representative of the position of the authors of this paper. All performance assessment can be authentic assessment, but not all authentic assessments are performance assessment. For example, some scholars (Chang & Chiu, 2005) insisted that even computer-based tests can be authentic assessment if the items are reflecting real-life situations. Nowadays computer-based modeling simulations have many embedded forms of assessment items in the simulations. The virtual experiment, interactive simulations, and games have authentic features reflecting real-world scenarios in the virtual environment. However, it is important to note that not all performances mirror real-life situations. For instance, students who are majoring in biology may need to perform sketching skills, however, the question may also be

posed to ask: is this still an important performance in learning biological knowledge? Nowadays we can use high quality cameras instead of sketching in the field.

Another way to consider the distinction between the forms of assessment is shown in *Figure 2*. If standardized, multiple-choice, paper-pencil tests are ‘traditional assessment’, and alternative assessment is the opposite of traditional assessment, authentic assessment need to be thought of as performance based. Given that when we use multiple-choice items with real-life situations, it can be authentic assessment, the overlap of authentic assessment and performance assessment is only partial, as shown in the figure.

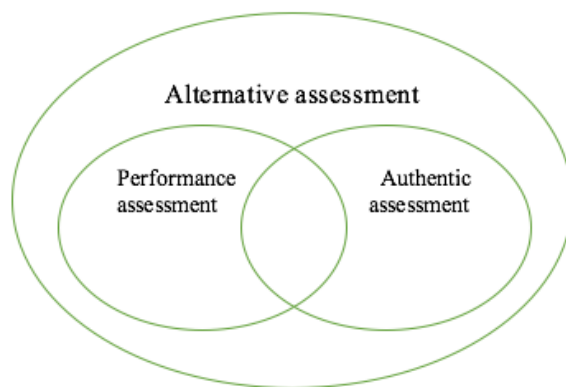


Figure 2.2 Relationship between authentic assessment, performance assessment, and alternative assessment.

Since the 1990s, authentic assessment has centered on meaningful real world tasks mostly measured by products or performances with realistic value out of school (Frey et al., 2012; Newman et al., 1998). Wiggins (2006) explained authenticity, noting that it “results in a product or presentation that has meaning or value beyond success in school.” (Wiggins, 2006, p. 51). According to Wiggins, authentic assessment should have realistic and meaningful values relevant to students’ lives outside the school environment. It should measure the ability to use skills to solve problems in realistic settings (Hushman et al., 2013; Wiggins, 1989). Lund (1997) explained that authentic tasks need to provide a meaningful context to connects real-world

experiences and school-based educational settings. In this sense, the learning experiences and assessment situation as real performance settings need to be aligned to present both the process and product of learning, and make indistinguishable the distinctions between instruction and assessment (Lund, 1997).

Wiggins (1993) pointed to the problem that decontextualized assessment causes with respect to validity. The author explained how competent performance requires students to link tasks to real-life contexts, and this linkage serves as the basis of judgment of students' readiness towards their future professional life situation (Wiggins, 1993). The existence of the linkage between real-life contexts and the judgment, which is made to evaluate the student, is also the basis of the claim for validity of the measure (Wiggins, 1993). Klassen (2006) explained how historically, the discussion of contextualization in assessment was influenced by the shift from the empiricist-behaviorist paradigm to a paradigm of cognitive psychology and constructivism. Kamen (1996) also emphasized the importance of contextualization related to validity of assessment, noting that "To have valid or authentic measures of what children understand, they should be evaluated in context." (p. 862).

Hein (1991) described what authentic assessment might look like;

We can assess students in a variety of ways: we can observe what they do, listen to what they say, read what they write, and analyze what they produce. Any behavior that can be perceived can be adapted for assessment. (p. 116).

Many articles suggested practical ways of examining how to implement authentic assessment strategies to better ascertain what students understand (Kamen, 1996). Kamen (1996) listed a variety of strategies used in the 1990s such as "performance assessment (Haury, 1993; Smith et al., 1993), portfolio assessment (Collins, 1992; Huary, 1993; Smith, Ryan, & Kuhs,

1993), observations (Hein, 1991; Raizen & Kaser, 1989), interviews (Meng & Doran, 1990), creative drama (Kamen, 1991), cooperative group assessment (Johnson & Johnson, 1991), journals (Raizen & Kaser, 1989; Smith et al., 1993), and concept mapping (Dana, Lorschach, Hook, & Briscoe, 1991; Roth, 1992).” (p. 862).

Essential Characteristics of Authentic Assessment

Scholars have emphasized different aspects of authentic assessment. Lund (1997) described seven characteristics of authentic assessment: “(1) Authentic assessments require the presentation of worthwhile and/or meaningful tasks that are designed to be representative of performance in the field. (2) Authentic assessments emphasize "higher level" thinking and more complex learning. (3) The criteria used in authentic assessment are articulated in advance so that students know how they will be evaluated. (4) Assessments are so firmly embedded in the curriculum that they are practically indistinguishable from instruction. (5) Authentic assessment changes the role of the teacher from adversary to ally. (6) Students are expected to present their work publicly. (7) Assessment must involve the examination of the process as well as the products of learning.” (p. 25-27). These seven features of authentic assessment are characterized as evaluating students’ integrated knowledge and skills which can be applied to real-life situations. Therefore, the evaluation of the process and products is important in authentic context which requires higher level of thinking.

Frey, Schmitt, and Allen (2012) examined the characteristics of an authentic classroom assessment in education in their comprehensive literature review. They reviewed articles from pre-school to college levels and job training. As Frey, Schmitt, and Allen (2012) noted, many articles related to authentic assessment were found at college level education, particularly in relation to teacher preparation or nursing. This seems reasonable in that authentic instruction and

assessment are imperative to the preparation for professional practices at the college level or vocational education. The authors extracted nine essential characteristics of authentic assessment framed within three broad areas of consideration: “(1) context of the assessment: realistic activity or context, performance-based task, cognitively complex task, (2) the role of student: a defense of the answer or product, formative assessment, collaborate with others, (3) the scoring: scoring criteria are known or student developed, multiple indicators or portfolios are used for scoring, and performance expectation is mastery” (p. 5). Interestingly, Frey, Schmitt, and Allen (2012) concluded that, in contrast to common assumptions of authenticity as “realistic”, the requirement of “realistic” context in the assessment was not often mentioned by researchers as a necessary characteristic of authentic assessment.

Gulikers et al. (2004) discussed five dimensions of authentic instruction and assessment and their alignment. The five dimensions of authentic assessment include: task, physical context, social context, criteria, and result. According to Gulikers et al. (2004), an authentic assessment task is one which resembles an authentic learning task, but in a new situation, requires integration of knowledge, skills, and attitudes. The physical context deals with the site or situation of the task and is linked to realistic nature of the task. In teacher education, this might refer to opportunities for professional practice in terms of the kind and amount of resources and time. The social context is described by the human contacts which happen related to task and might be changed, for instance, by have the task takes place out of school. The authors further argued that authentic criteria should be used in situations that help the learner develop knowledge related to real life, including relevant competencies for future (professional) life. Also, the assessment criteria are known beforehand (Lund, 1997), so it is transparent and explicit to students how they are assessed (Gulikers et al., 2004). In some cases, criteria are developed by

students (Frey et al., 2012; Lund, 1997). Authentic assessment result shows demonstration of competencies, presentation, reflected from multiple indicators of learning (Gulikers et al., 2004).

Based on work of scholars' addressing the characteristics of authentic assessment, most particularly the work of Lund (1997), Gulikers et al. (2004) and Frey et al. (2012), the necessary characteristics of authentic assessment are: resemblance of realistic context either physical or social context (e.g. collaboration with others), performance-based task, mastery expectation, embedded in curriculum, transparent and explicit criteria to students, some form of formative assessment, and multiple indicators of task accomplishment.

Authentic Assessment in K-12 Science Education

At this point in this paper, the focus is shifted to the review of literature related to authentic assessment in K-12 science education. As noted above, many studies of authentic assessment in science education are related to teacher education programs or trainings such as assessing teachers' readiness and their knowledge and practice, in particular, in the context of prospective teacher preparation.

A primary motivation for this literature review is to continue the investigation of MOA as an authentic assessment. Namdar & Shen's (2015) MOA framework was developed by studies only focused on K-12 levels. As we extract the characteristics of MOA from Namdar & Shen's (2015) work and compare MOA and authentic assessment, we delimited the search to science specific studies conducted at the K-12 levels. After examining how and what types of authentic assessment tasks have been conducted in science classrooms, we then look at prospective teachers' understandings of MOA in relation to authentic assessment from the literature. In the PART II: 'MOA and Prospective Science Teacher Preparation' section, due to scarce literature in prospective teachers' understanding of MOA for K-12 science teaching, first we examine

modeling literature in relation to prospective teachers, then extract PSTs' understanding of assessment of models and modeling. Then, we will discuss the implications of the examination of the MOAA in K-12 science education to science teacher preparation.

(Note of clarification: Understanding of MOA does not mean the understanding of MOA framework of Namdar & Shen (2015). Understanding of MOA encompasses how prospective teachers understand assessment of models, assessment of modeling practice (process), or assessment of meta-modeling knowledge of students in K-12 levels.)

There was no consensus definition of “authentic assessment” among the selected articles related to K-12 science teaching, but the characteristic they shared was an emphasis on real-world tasks. It seemed that the essential characteristic for authentic assessment was “contextualization” (Klassen, 2006, p. 832) in its reflection of a real-life situation rather than the knowledge probes of traditional assessment. In comparison to traditional assessment which is usually decontextualized, ‘contextualization’ is the necessary trait of the authentic assessment which makes authentic assessment to be authentic. Gulikers et al. (2004) defined *authentic assessment* as: “an assessment requiring students to use the same competencies, or combinations of knowledge, skills, and attitudes, that they need to apply in the criterion situation in professional life” (p. 69).

Table 2.1 shows the list of articles centered around authentic assessment in science education at the K-12 levels.

Table 2.1 Authentic Assessment Articles in Science Education Focused on K-12 Levels.

	Authors	Grade levels	Format of assessment	Assessment (learning) Goals	Subject/topic	Criteria	Social context (instruction)	Social context (assessment)
1	Anker-Hansen & Andr��e (2015)	8th grade (41 students) in Sweden	Observation of debate (videorecording)	1) stay in true to one's role, 2) expressing social responsibility, 3) winning the debate, and 4) using sources critically.	a socio-political debate (A decline in the yield of fish in a lake (acidity & toxicity))	Reasoning and arguments, use of information, communications	Group	Group
2	Bouwma-Gearhart & Bouwma (2015)	High school biology	Individual written assessment, presentation, ethograms (model construction)	(1) Construct an ethogram of their assigned cricket, (2) Constructing a model and revise the model.	Biology	(1) Students' ability to construct and revise scientific models, (2) understanding of how to judge the strength of models (empirical and conceptual consistency and predictive power), and (3) ability to communicate about all of this.	Group	Individual
3	Liu, Lee, & Linn (2011)	Middle & high schools	Online items: EMC (explanation multiple-choice), Short-response items, Constructed-Response Items	knowledge integration	Web-based Inquiry Science Environment (WISE, http://wise.berkeley.edu)	knowledge integration	N/A	Individual
4	Koh & Luke (2009)	Elementary and high school	Filling out graphic organizer with reading a context, Sustained writing	The relationship with quality of teachers' assessment tasks and students work		(1) Connections to the real world beyond the classroom, (2) knowledge criticism, (3) depth of knowledge, (4) knowledge manipulation, (5) sustained writing.	individual	individual
5	Houtz & Quinn (2006)	Middle level students	Knowledge pre/post-test, ATSSA (attitude), journals, lab sheet, quiz, K-W-L chart (content knowledge), accurate construction (models)	Evaluate the attitude, content knowledge, and process skills	Health science/biology	Molecule model construction (Accuracy of model) & cell model construction (Accurate construction)	Group (K-W-L chart, lab sheet, journal) & Individual (model constructions, ATSSA, etc.)	Group (K-W-L chart, lab sheet, journal) & Individual (model constructions, ATSSA, etc.)

	Authors	Grade levels	Format of assessment	Assessment (learning) Goals	Subject/topic	Criteria	Social context (instruction)	Social context (assessment)
6	Chang & Chiu (2005)	Ninth's grades in Taiwan (44 schools)	Multiple-choice items, open-ended questions, hands-on activity (process skills), & Likert scale items (attitude)	Evaluating scientific literacy: scientific cognition, application of science, habits of mind, process skills, competence-based assessment.	Chemistry and Physics	Understanding of chemical reactions, Understanding of the reactions of acid and base with indicators, & Distinguishing an unknown solution as an acid or a base using a universal indicator in hands-on activity.	Individual	Individual
7	Schnitzer, Sandra (1993)	High school students	Observation, Self assessment using McREL 14 complex thinking processes	Assessment of decision-making / visual representation of their decision	Advanced biology	Identification of criteria, presentation of the criteria in detail, and understanding for the repercussions of the decision, Five criteria for the decision making: hostage safety, public opinion, world opinion, economic repercussions, potential for war, more kidnapping)	Group	Group
8	Doran et al. (1992)	High school students	Teacher's notes (observation), assessment sheet, scoring form for laboratory test (criteria and Likert scale)	Two-stage testing format (Planning, Performing, and Reasoning)	Diffusion	Lab skills assessment (1) Experiment design: statement of hypothesis, procedure for investigation, plan for recording and organizing observations/data (2) Experiment report: quality of observation/data, graph, calculations, forms a conclusion from the experiment	Group	Individual
9	Kamen, M (1996)	4 th grade students	Creative drama (with checklist), scrapbook(I), meal maps with essays, and student logs (snail books), observation		Animals	Students' understanding of content/concepts, misconceptions, Clear explanation of what students did (student log).	G/I	Individual

From *Table 2.1* we can find the many different formats of authentic assessment that have been attempted in K-12 science classrooms. According to the literature, when teachers and researchers tried to assess student learning outcomes by authentic assessment, they mainly used observations using teachers' notes (Doran et al., 1992), observations in hands-on activities, laboratories, and model development (Bouwma-Gearhart & Bouwma, 2015; Houtz & Quinn, 2006). However, we can also find many other formats of authentic assessment such as written responses, presentation, portfolio, creative drama, scrapbook, visual representation, concept maps, journals, and multiple-choice items. Figure 2.3. shows the summary of the authentic assessment task formats in K-12 science education.

Prominent Features: Assessment Characteristics

It is important to note that there are examples of multiple-choice items in standardized tests that are labeled as authentic assessment (Chang & Chiu, 2005; Liu, Lee, & Linn, 2011). Chang & Chiu (2005) addressed how in the past decade, standardized testing and authentic assessment have been perceived as very different avenues, however, “standardized and authentic assessment have started to merge for evaluating students' higher-order of thinking skills” (p. 120). In the sense of authenticity as mirroring real-life situations to instruction and assessment, the Chang & Chiu (2005) development of assessment items that students can apply to school knowledge in a real-life context in the form of multiple-choice items can be considered as authentic assessment. However, most tasks used to measure student knowledge within authentic assessments are performance-based assessment. *Figure 2.3* shows the frequency of performance tasks used in studies of authentic assessment of K-12 science education in our collection (nine articles).

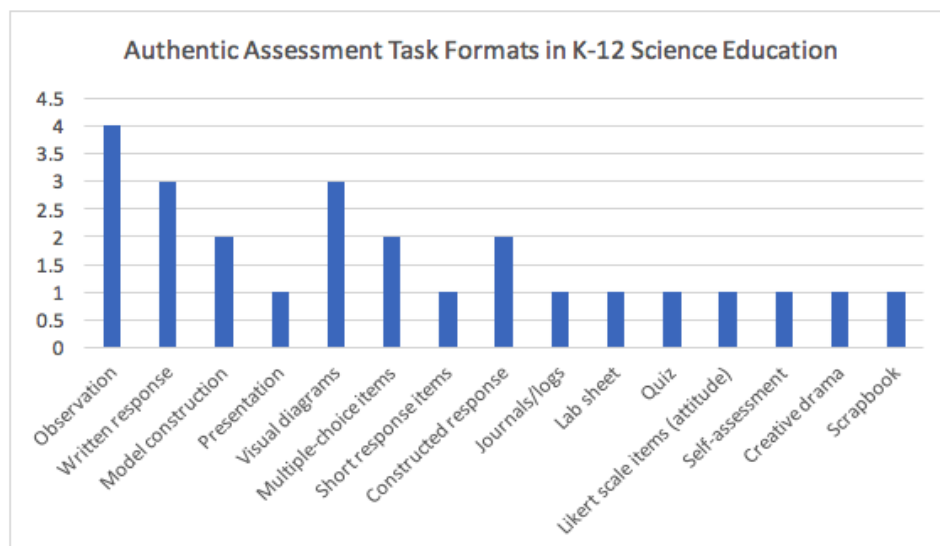


Figure 2.3 Authentic Assessment Task Formats in K-12 Science Education

Kamen's (1996) paper reported on a 4th grade teacher, Virginia, and her year-long attempts to implement authentic assessments strategies. Virginia showed the shifts toward an integrated approach where in alignment of assessment and instruction occur simultaneously to assess what students learn. She tried authentic assessment strategies with diverse formats during a curriculum unit on animals. Virginia decided to have her 4th students to engage in learning experiences as diverse formats such as observation, creative drama (with checklist), scrapbook, meal maps with essays, and student logs (snail books), interview as well as traditional tests. For example, Virginia used creative drama to assess students' understanding of content. Also, she used interviews as an assessment strategy with pairs of students and individuals. In this study, Kamen (1996) pointed out Virginia's being uncomfortable about the overlap between instruction and assessment. Kamen (1996) explained how, in Virginia's self-report of her thinking, the teaching during a planned assessment did not fit her image of teaching first and assessment second. And, it took a great deal of time for Virginia to become comfortable with the integration of instruction and assessment. Furthermore, Virginia noticed students used more effort and

demonstrated what they learned when they were aware of being evaluated in lessons, at the same time, she noticed students were learning from assessments also. One of the important findings from this study was that, due to the integration of instruction and assessment, her skills related to helping students to complete an assessment was developed. Also, Virginia recognized that the variety of assessment modalities gave her a more complete picture of what students understand and increase the validity of her assessments.

Figure 2.4. shows the authentic assessment goals in K-12 science education from the literature.

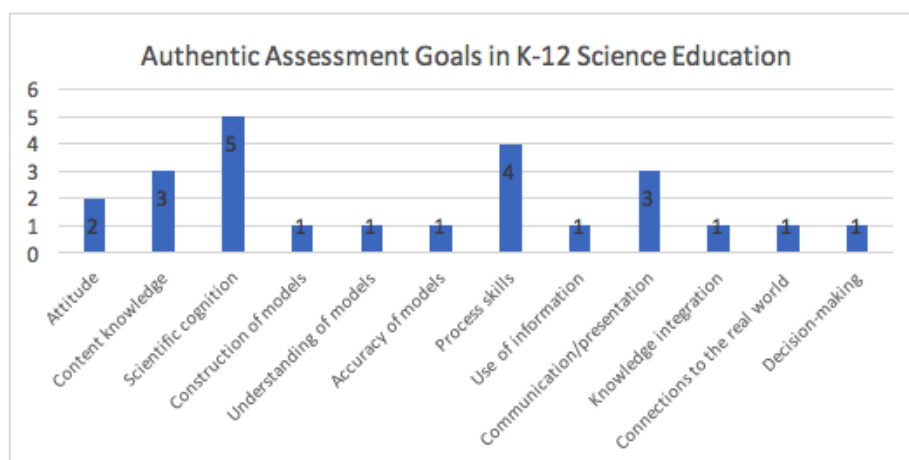


Figure 2.4 Authentic Assessment Goals in K-12 Science Education

I found that very few studies examined authentic assessment with elementary level students. Authentic assessment has been attempted more commonly at the secondary science level. Liu, Lee, & Linn (2011) conducted online standardized test items with 18,729 middle and high school students to assess knowledge integration. The authors claimed that science assessments typically measure recall facts and basic concepts of isolated information. They used EMC (explanation multiple-choice), Short-response items and Constructed-Response Items to make the test more authentic, reflecting real-life contexts in the assessment items. They had

students respond with additional explanation to their multiple-choice selections and used short-response and constructed-response items as well. In Gulikers's et al. (2004) five dimensions of authentic assessment, physical context is included as one of the dimensions. Physical context needs to resemble a realistic context and professional practice in terms of the kind and amount of resources and time (Gulikers et al., 2004). In multiple-choice items, we cannot find a resemblance to the physical context. However, with the agreement of 'authenticity' as reflective of a real-life situation, we can consider multiple-choice items as authentic assessment as well. With the importance of cost effectiveness as a major issue in the needs of state or nation-wide high-stakes tests, authentic science assessment needs to be considered and attempted in the form of multiple-choice or short-response items even if it can offer a minimal authentic physical environment (Liu, Lee, & Linn, 2011).

Figure 2.5 shows the social context and subject/topic area of authentic assessment in K-12 science education.

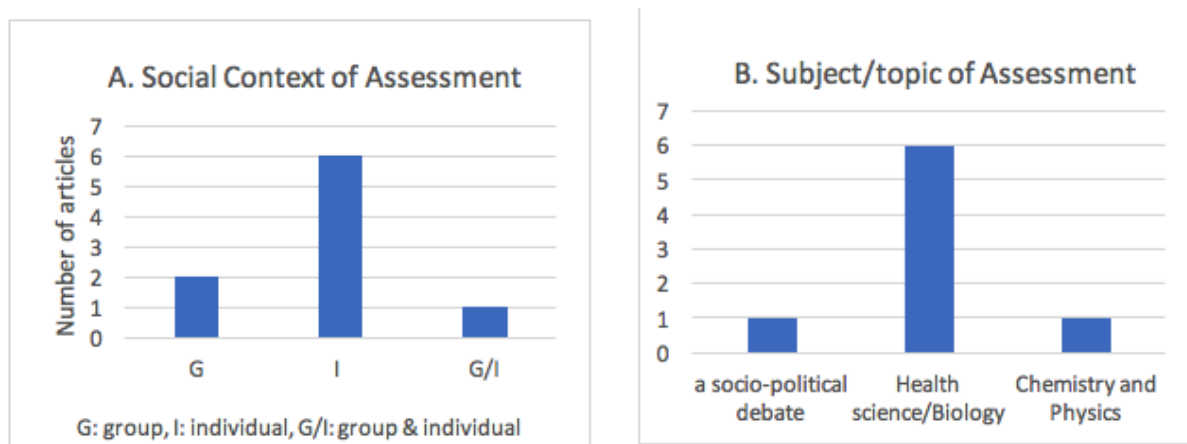


Figure 2.5 Authentic Assessment Environment in K-12 Science Education (A. Social Context of Assessment, B. Subject/topic of Assessment)

In many studies, the effectiveness of authentic learning environments and authentic assessment strategies have been reported. However, Nicaise, Gibney, & Crane's (2000) study

addressed how students struggled with the authentic learning environments. In many cases, the learning gains in authentic environments are made when there is student ownership (Gobert, 2000). The authors found that authentic environment required students to integrate multiple contents and skills which is very active learning approach. However, the students' struggles were from their lack of sufficient background knowledge. Nicaise, Gibney, & Crane's (2000) concluded that "The idea that classroom learning needs to be entirely situated around student interest or project ideas may be an idealistic notion, at least for now." (p. 92). Their findings imply many important issues. In this sense, authentic assessment is an ideal form of assessment, but it needs to be scaffolded for students to be engaged in and meaningfully done in classroom settings. The authors questioned whether authentic learning classrooms help students to transfer learning to new and real-world situations or not is important to think about. Another question posed by the authors is the extent and to what level the authentic tasks need to be accomplished or what the authentic tasks look like in elementary or middle level students. Additionally, there is the question of cost for effective authentic assessment in relation to learning expectations in authentic learning.

Among articles related to authentic assessment in science education, one of the forms of authentic assessment was model construction (Bouwma-Gearhart & Bouwma, 2015; Houtz & Quinn, 2006). Bouwma-Gearhart & Bouwma's (2015) study is directly related to modeling and MOA. The authors examined how high school students created a conceptual model to account for both natural and sexual selection using the case of the Texas field cricket (*Gryllus texensis*). The students progressively developed and revised their model based on more evidence and information. Interestingly, the male cricket has a dilemma. The male cricket's mating song attracts the female cricket for mating. But at the same time, the song attracts a parasitoid fly

(*Ormia ochracea*) which lays its eggs on the male crickets, eventually killing them. In this guided inquiry, students experienced model construction and revision to explain the complicated relationship among populations. Students were given data such as graphs of number of visits by female crickets and female flies per pulses of artificial “male” cricket calls. In this modeling process, Bouwma-Gearhart & Bouwma (2015) found that students were given opportunities for authentic assessment of their growing content knowledge, modeling skills and communication processes. They implemented the authentic assessment by asking students to construct an explanation for the phenomenon with their existing knowledge of selection and related variables. Also, the authors tried to assess students’ meta-modeling knowledge about the nature and purpose of models and modeling (Schwarz and White, 2005). For example, students were asked to describe their revision process of modeling (Meta-modeling), evaluate the “strength” of their own models (Meta-evaluation), and think about the roles of scientific models in the scientific community (Meta-model). (Meta-model, modeling, and evaluation are from the categories of MOA).

Based on the performance-based characteristics of authentic assessment, Anker-Hansen & Andrée (2015) and Klassen (2006) discussed the reliability of assessment. The goal of authentic assessment is to achieve high validity to measure what students learn from the instruction in an authentic learning context (Anker-Hansen & Andrée, 2015). The relationship between validity and reliability in authentic assessment seems like a trade-offs in assessment tasks. Anker-Hansen & Andrée (2015) explained this issue and how we can implement authentic assessment with appropriate validity and reliability.

In sum, striving towards greater validity by means of authenticity and performance assessment offers challenges for achieving reliability. Thus in authentic assessment, the

concept of a ‘fair’ assessment task is very complex, and teachers have to negotiate ‘fairness’ in relation to the assessment task Instead, reliability might be attained through the use of multiple assessment tasks to create a better holistic picture of student competences (Anker-Hansen & Andrée, 2015, p. 2581).

Anker-Hansen & Andrée (2015) pointed out that the use of multiple assessment tasks built evidence of reliability through triangulation of measuring what students learn and what students can do.

To summarize, as Kjoernsli and Jorde (1992) argued, there is a need for assessment and instrument development beyond testing factual knowledge. Kamen (1996) noted that assessment items should assess how children are learning science and be able to identify students’ misconceptions in science learning. To achieve these goals, authentic assessment in science education has been developed and implemented in many different formats. Additionally, Klassen (2006) emphasized the struggles in administrating the authentic assessment in terms of student ownership, time and cost effectiveness, validity and reliability.

MOA (Modeling-Oriented Assessment) in Science Education Linkage to Authentic Assessment

Based on the literature on authentic assessment in science education, model construction and modeling process are discussed as authentic assessment strategies (Bouwma-Gearhart & Bouwma, 2015; Houtz & Quinn, 2006). Since modeling is one of the core scientific practices, through modeling practice, students can learn the process of science and how to do science similar to what scientists do either in hands-on or technology-based learning environment (Kuhn, 2005; NRC, 2012; Schwarz et al. 2009). In the modeling process, we also can measure students’

modeling skills, knowledge integration in model construction as well as conceptual understandings (Louca & Zacharia, 2008). In addition, students learn modeling as a scientific practice in scientific inquiry when they are engaged in modeling activities. In this sense, teachers' recognition of authenticity in MOA (modeling-oriented assessment) is directly related to the plans and implementations of modeling and its assessment in science teaching with an integrated understanding of the process of instruction and assessment.

Gulikers et al. (2004) emphasized the consistency between learning and assessment in authentic assessment. This idea is also consistent with the 'Backward Design' framework for lesson design (Wiggins and McTighe, 2005), starting with learning goals and assessment tasks to instructional planning. As Gulikers et al. (2004) noted, "Learning and assessment are two sides of the same coin, and ...they strongly influence each other. To change student learning in the direction of competency development, authentic competency-based instruction aligned to authentic competency-based assessment is needed" (p. 68). Likewise, with the emphasis on modeling practice in NGSS, modeling also needs to be used in the assessment of student learning outcomes.

Gilbert (2004) asserted the characteristics of authenticity in modeling, describing how modeling represents science processes in terms of social aspects and creativity when models play the role of providing satisfactory explanation of phenomena. Authenticity in modeling also can be reflected in assessments using models and modeling, and MOA. Namdar and Shen (2015) explained, "modeling tasks can also serve as an authentic environment in which students develop and apply various scientific practices similar to what scientists do." If we are aiming for science instruction with models and modeling implemented with fidelity, MOA needs to be practiced in

an authentic way in science classrooms. Table 3 shows the characteristics of MOA as authentic assessment.

In recent years, researchers have paid more attention to model evaluation as well as modeling as a tool for assessment. Namdar and Shen (2015) have synthesized assessment using models and suggested a framework for modeling-oriented assessment (MOA). Windschitl et al. (2008) promoted students' development of models and revision of these models based on new evidence and information in classroom settings. In the process of their own model creation and revision, students in Windschitl's et al. (2008) study were able to participate in scientific processes and experience the model's changing nature, rather than just learn 'established science' in the textbook. Louca and Zacharia (2008, 2015) noted how the absence of interactions among components in a student-constructed model could be translated into an absence of understanding of how the phenomenon/system functions. In this sense, MOA provides a meaningful approach to student assessment, reflecting the scientific communities' work and culture in the form of *authentic assessment* (Litchfield & Dempsey, 2015).

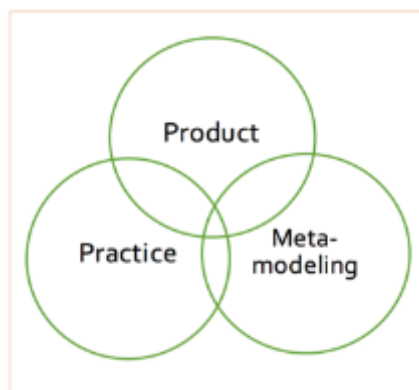


Figure 2.6 The three dimensions of MOA (Namdar & Shen, 2015)

Figure 2.6 shows the MOA framework and its three dimensions. Also, in *Table 2.2* MOA criteria in three dimensions are listed. Namdar and Shen (2015) introduced the framework

of MOA which is defined as, “both a way to determine students’ status with respect to variables of interest from a modeling perspective and a way to enhance student learning through modeling” (p. 5). MOA encompasses three dimensions: (a) assessment of student-generated models, (b) assessment of modeling knowledge and abilities demonstrated in modeling practices, and (c) assessment of meta-modeling knowledge.

Table 2.2 MOA Criteria in three dimensions

MOA Criteria (Namdar & Shen, 2015)
Assessment of Modeling Products Quality of a Model Construct Quality of a Model Representation Coherence of a Model as a Whole
Assessment of Modeling Practices Model Planning Model Construction Model Interpretation Model Evaluation Model Revision
Assessment of Meta-modeling Knowledge Nature of Models Nature of the Process of Modeling Evaluation of Models Purpose and Utility of Models

Authenticity in Modeling-Oriented Assessment

Gulikers’s et al. (2004) definition of ‘authentic assessment’ informed the development of this paper. Authentic assessment refers to assessments that align with the same skills that required of the student to complete a learning task and as such mirrors assessment in real-world settings (Gulikers et al. 2004). And, this real-world setting includes practices which scientists engage in as part of culture and competencies informed citizens apply to science to every life. To reiterate, authenticity in this paper is operationally defined in two ways: 1) similarity of task,

context, knowledge and skills required for professional practices or real-life situation and 2) alignment of assessment with instruction that students are engaged in.

When Namdar and Shen (2015) built the MOA framework, they also discussed the authenticity of MOA. They paid attention to “unit of analysis, assessment medium, and complexity” of MOA (p. 22). What they call “unit of analysis” means the unit of modeling activities they analyzed (collective/individual) in the MOA articles. This is the same concept as Gulikers et al.’s (2004) interaction form in the social context of the authentic assessment, and ‘collaboration with others’ in Frey’s et al. (2012) nine essential characteristics in authentic assessment. Namdar and Shen (2015) found, in their review of the literature on MOA, that most modeling practices conducted within activities that were individual-based. Collaboration is an essential feature of scientific practice, and also a lot of modeling activities are promoted collaboratively in classroom settings (Gilbert & Boutler, 2000; Gobert & Pallant, 2004; Lehrer & Schauble, 2006). In school science, it is an important to note that assessing collaborative modeling is not an easy task due to fairness and accountability of individual students in a group. However, developing rubrics on how to measure collaboration in the modeling process would be a meaningful task when it comes to the alignment of assessment with the learning environment.

Secondly, Namdar and Shen (2015) found a discrepancy between the media with which students engaged during their modeling activities and the media that they assessed. As we know there are always issues of validity and reliability in authentic assessment. Paper-and pencil tests, written responses, and multiple-choice response, either paper-and pencil or online tests, are prevalent in assessment even though most modeling activities depend on physical or computer-based materials (Namdar & Shen, 2015). However, it is important to note that individual written formats such as essays oftentimes require higher order of thinking and knowledge integration

depending on the nature of the assessment task. In addition, the complexity of MOA in assessing the learning process generates unwillingness to use MOA in science classrooms. The three dimensions of MOA described by Namdar and Shen, 2015 (modeling product, modeling practice, and meta-modeling knowledge) are closely interrelated with each other and MOA's performance- and process-based nature generates much complexity.

MOAA (Modeling-Oriented Authentic Assessment)

In this section, we discuss the characteristics of MOAA (Modeling-Oriented Authentic Assessment) which are found in this paper, as adapted from the MOA framework (Namdar & Shen, 2015). The reason why we coined the MOAA is to emphasize MOA as an 'authentic assessment'. We want to discuss the characteristics of MOAA and its potential in science education. MOAA places a stronger emphasis on assessment context for authenticity for promoting practical uses of modeling instruction and assessment. As suggested by previous research, MOA has many significant features of authentic assessment.

Modeling can be viewed as a process to learn science, learn about science, and learn how to do science. From the perspective of authentic assessment, assessment is feedback on the learning process. One of the characteristics of authentic assessment is formative assessment toward the expectation of mastery of the concept of interest. In this sense, thinking about MOA as feedback (Namdar & Shen, 2015) for continued learning is fit and meaningful to the notion of authentic assessment in that students can be engaged in modeling as a scientific practice similar to what scientists do, construct their scientific knowledge through modeling and be provided valuable feedback with respect to their learning and modeling process.

Table 2.3 Characteristics of MOAA (MOA as Authentic Assessment)
 (Adapted from Guliker's et al. (2004) five dimensions of authentic assessment)

	Authentic Assessment	Modeling-Oriented Assessment
Task	<ol style="list-style-type: none"> 1. Representation of performance in the field. (Lund, 1997) 2. Alignment with authentic instruction: resembles authentic learning task (Gulikers et al., 2004), firmly embedded in the curriculum (Lund, 1997) 3. Integration of knowledge, skills, attitudes in a new situation (Gulikers et al., 2004), cognitively complex task (Frey et al., 2012), higher level thinking & more complex learning (Lund, 1997). 	<ol style="list-style-type: none"> 1. Modeling practices similar task to scientists' work (Gilbert, 2004). 2. Alignment with modeling instruction and assessment (Namdar & Shen, 2015). 3. Integration of knowledge, skills, attitudes of modeling to construct models (Namdar & Shen, 2015). 4. Engaging learners in integrative, meta-cognitive modeling process (Namdar & Shen, 2015).
Physical context	<ol style="list-style-type: none"> 1. Resembles realistic context/professional practice (Gulikers et al., 2004) 2. Kind and amount of resource, time (Gulikers et al., 2004) 	<ol style="list-style-type: none"> 1. Evaluation in modeling process: constructing, revising, interpreting models (Namdar & Shen, 2015). 2. Modeling processes require additional time in a modeling curriculum (Namdar & Shen, 2015).
Social context	<ol style="list-style-type: none"> 1. Similar to social context in which the task takes place out of school (Gulikers et al., 2004) 2. Collaborate with others (Frey et al., 2012) 	<ol style="list-style-type: none"> 1. Similar to communities of scientists (Newton et al., 1999) 2. Collaboration in modeling process (teamwork & individual roles) (Gilbert & Boutler, 2000).
Criteria	<ol style="list-style-type: none"> 1. Criteria used in real life, relevant competencies for future (professional) life (Gulikers et al., 2004) 2. Examination of process as well as product (Lund, 1997) 3. Transparent & explicit beforehand (Gulikers et al., 2004), articulated in advance (Lund, 1997), scoring criteria are known or student developed (Frey et al., 2012) 	<ol style="list-style-type: none"> 1. Criteria used by experts' views on model evaluation (e.g., number of variables, accuracy of models) by using multi-component rubric (Namdar & Shen, 2015). 2. Examination of modeling process, meta-modeling knowledge as well as modeling product (Namdar & Shen, 2015). 3. Criteria are known beforehand (Kamen, 1996). 4. Evaluation of learners' understanding of variables, relationships among variables in models, analogy between the source and the target (Namdar & Shen, 2015).
Result	<ol style="list-style-type: none"> 1. Demonstration of competencies, presentation (Gulikers et al., 2004) 2. Multiple indicators of learning (Frey et al., 2012; Gulikers et al., 2004) 	<ol style="list-style-type: none"> 1. Demonstration of modeling competencies, presentation of models (Papaevripidou et al., 2014). 2. Use of multiple forms of models and modeling as multiple sources of data to evaluate student learning (Wu, 2010). 3. Giving valuable feedback on students' modeling (Namdar & Shen, 2015).

Summary

In this section, we reviewed MOA as authentic assessment. We started the review with the emergence of authentic assessment in education. The authentic assessment began with the criticism of standardized testing in 1990s, referring to direct examination of student performance in realistic tasks (Worthen, 1993a).

Many scholars introduced the essential characteristics of authentic assessment (Frey et al., 2012; Gulikers et al., 2004; Lund, 1997). In this paper, we adopted Gulikers's et al. (2004) five dimensions of authentic instruction and assessment, then combined with other scholars' essential characteristics of authentic assessment, mainly based on the work of Lund (1997) and Frey et al. (2012). Then, we examined authentic assessment in K-12 science education with identified nine articles. The prominent features of authentic assessment in K-12 science education were: 1) there are diverse forms of assessment formats exist as well as observation which used as a main tool for authentic assessment, 2) assessment goals were to evaluate mainly students' scientific cognition, process skills, content knowledge, and communication/presentation. 3) interestingly, social context of authentic assessment was mostly individually based. And 4) most authentic assessment topics in science education were health science/biology. Then we looked at the linkage between MOA and authentic assessment by comparing the essential features of both constructs. MOA showed a good match to 'authentic assessment' in science education. We coined the term, MOAA (Modeling-Oriented Authentic Assessment) with emphasis on MOA as an 'authentic assessment'.

PART II

MOA (Modeling-Oriented Assessment) and Prospective Science Teacher Preparation

In this section, I describe prominent themes traversing the literature about models and modeling related to the preparation of prospective science teachers. Generally, literature about models and modeling is concentrated on K-12 education and students in relation to conceptual change, inquiry and the nature of science (NOS). I reviewed the literature focused on models and modeling in relation to the preparation of future teachers and professional development programs for prospective teachers.

Methods

Similar to the search on authentic assessment in section 1, I used an ERIC search as a main source. I researched the most recent two decades (from 1998 to 2016) and included only peer-reviewed, empirical research articles. Also, the articles were selected, published only English and relate to science content. If a study only looks mathematical modeling of PSTs, we excluded that article. In addition, if the modeling strategy is used for enhancing PSTs' content knowledge of specific discipline, but not research on PSTs' understanding of science teaching with the modeling for future students, the article was excluded because our interest is prospective teachers' pedagogical content knowledge on modeling. Various combinations of the following keywords were used in the search:

(Keywords: "modeling") and (Keywords: "science teacher education"), (Keywords: "scientific model") and (Keywords: "teacher education"), (Keywords: "modeling") and (Keywords: "science teacher education") and ("assessment"), (Keywords: "Pre-service") and

(Keywords: Modeling") and (Keywords: "science"), (Keywords: "Pre-service") and (Keywords: "Modeling") and (Keywords: "science education"), (Keywords: "Pre-service" and "Modeling-based") and (Keywords: "science education"), (Keywords: "Pre-service") and (Keywords: "Modeling-based") and (Keywords: "teaching"), (Keywords: "Modeling-based") and (Keywords: "science teaching"), (Keywords: "Modeling-based") and (Keywords: "science learning"), (Keywords: "Modeling-based") and (Keywords: "science instruction"), (Keywords: "Modeling-based") and (Keywords: "science learning") and (Keywords: "preservice"), (Keywords: "science") and (Keywords: "preservice teacher") and (Keywords: "modeling assessment").

Based on the above criteria, 16 articles were selected from among 121 articles in science teacher education related to modeling from the initial search. After the articles were included in our collection, we coded the individual articles based on a coding schema that included study information (e.g. author, year, title, source, research interest, sample size, data source, subject, research design, and findings). The review of these articles on prospective teachers' understanding of modeling is summarized in the *Appendix A*.

To synthesize the two different constructs, MOAA and preservice teacher education on modeling, when we searched with (Keywords: "teacher") and (Keywords: "Modeling") and (Keywords: "authentic assessment"), only one article was found: Bouwma-Gearhart, J; Bouwma, A (2015) article, *"Inquiry through Modeling: Exploring the Tensions between Natural & Sexual Selection Using Crickets"*. However, this article is not describing research about prospective teacher education. When we searched with (Keywords: "preservice") and (Keywords: "scientific modeling") and (Keywords: "assessment"), we could find one article: Adams, S.T. (2004) *"Commentary: Considerations in Pedagogy and Assessment in the Use of Computers to Promote Learning about Scientific Models"*. This article was excluded in our literature collection because

it is commentary, but we felt we needed to refer to the article. Adams (2004) proposed a new method to assess students' knowledge of modeling: how students interpret news reports of scientific findings derived from models from *Time* magazine. Adams (2004) mentioned that this example was from his own study of high school students' interpretation of a news report. The author suggested knowledge of modeling as a critical 'scientific literacy'.

MOAA and Teacher Preparation

In the following section, we will discuss what research says about prospective teachers' knowledge of modeling, and what are the challenges and areas of success in preparing teachers to teach modeling. In the concluding section of the manuscript, we will discuss how this synthesis of research provides direction on the implementation of MOA as a form of 'authentic assessment' and what the implications of the examination of articles on MOAA for prospective teachers' learning on models/modeling. This research synthesis produced five themes that describe the relationship between Model Oriented Assessment and teacher preparation. Those themes are: (1) Research Focuses on Teachers' Knowledge about Modeling, (2) Importance of Experience with Modeling & Incorporating in Instruction, (3) Prospective Teachers Struggle with Learning Models and Modeling, (4) Prospective Teachers' Understanding of Modeling with Technology, and (5) Few Studies Have Been Conducted on Prospective Teachers' Views of the Assessment of Modeling. In the upcoming sections of this chapter, the literature related to these themes will be described. At the conclusion of this section, the tensions which connect these themes to MOA will be described in relation to implications in science teacher preparation.

Challenges for Teaching Prospective Teachers about Models and Modeling

Research Focus on Knowledge of Modeling of Prospective Teachers

The first theme arises from recent research literature on prospective teacher education that is focused on models and modeling. This work allotted greater attention to teachers' knowledge rather than teachers' perceptions, attitudes, beliefs, and interests. Many researchers examined the reasons why there has been limited adoption of modeling practices in schools. These studies generally highlight to issues: (1) teachers' limited knowledge about models and modeling; and (2) students' thoughts about modeling (Kenyon et al., 2011, p. 3). Among the studies on teachers' knowledge, and in particular their pedagogical content knowledge, most of their focus was on prospective teachers' knowledge about models and modeling. The concept of 'meta-modeling knowledge' (Schwarz and White, 2005) is a central feature of this work, and includes the study of such concepts as what a model is and the components, functions, roles, and modes of models (Crawford & Cullin, 2004; Daunsso et al., 2010; Frede, 2008; Kim, 2015; Kenyon et al., 2011; Nelson & Davis, 2012; Ogan-Bekiroglu, 2006; Schwarz, 2009; Windschitl & Thompson, 2006).

Two studies were found that examined prospective science teachers' perceptions (Ogan-Bekiroglu, 2006) and self-efficacy (Nelson & Davis, 2012) about models and modeling. Ogan-Bekiroglu (2006) found that prospective teachers perceived modeling as an effective teaching strategy. Surprisingly, though, even with this positive endorsement of modeling, she found that there was no statistically significant difference in their pedagogical knowledge when it came to teaching modeling. This study indicates that the "implementation of the model-based teaching in the pre-service teacher education program did not make too much difference in the pre-service physics teachers' general knowledge of models" (p. 1) between a control group and the

experimental group. However, Ogan-Bekiroglu (2006) suggested that the mode of the model constructed used in the model-based teaching might generate some differences in the knowledge of prospective teachers in terms of characteristics, roles and functions of models. These findings emphasize the importance of how and what kinds of models and modeling practice should be presented in a teacher preparation course. The main activities having to do with modeling in this article were discussions about articles on models and modeling and were not focused hands-on activity or even constructing a model (the only modeling activities were conducted by concept mapping and experiences with modeling software). The prominent features of Ogan-Bekiroglu's (2006) study was its explicit mention and discussion of modeling in a methods course. In addition, they found a relationship between perceptions and knowledge of teachers. Their results showed a need to consider promoting prospective teachers' knowledge base for teaching modeling as much as positive perceptions of modeling to encourage the use of modeling in teaching. But, due to the nature of a quantitative study, there was no mention about how these unbalanced relationships might influence prospective teachers' practices.

Similarly, from the Namdar & Shen's (2015) MOA article, on assessment of modeling in K-12 levels, they reported that many studies also focused on assessment of scientific understandings through modeling rather than other domains such as process skills or affective domains. If the MOA is to serve as an authentic assessment, the assessment task must assess the integration of knowledge, skills, attitudes of modeling in a new situation. To do this in a comprehensive fashion, the MOA framework suggests three areas of assessment: models, modeling, and meta-modeling knowledge. From the review of literature (Namdar & Shen, 2015), we learned that prospective teachers learning has been mostly focused on knowledge of the nature of models and modeling, rather than on the process of modeling or affective aspects of

modeling. However, Bouwma-Gearhart & Bouwma's (2015) study on authentic assessment using modeling, addressed how students developed content knowledge, modeling skills and communication processes through modeling process. When we think about Kamen's (1996) study, Virginia's becoming comfortable with the integration of instruction and assessment, and recognition of the benefits of this integration for students learning, can inform teacher educators that instruction for prospective teachers needs to emphasize the importance of integration of between instruction and assessment. And further, this work also points to a need for teacher education instruction to emphasize the role of validity within the great variety of assessment modalities in teacher preparation. Likewise, in model-based instruction, MOA serves as a foundation through which prospective teachers can be prepared to teach science with this integration and validity. In addition, prospective teachers can develop the skills to help students to complete planned assessments in modeling instruction like Virginia.

Research on prospective teachers' understanding of models/modeling needs to be more comprehensive, including models, modeling practices, and meta-modeling knowledge. Also, we found there are few studies in prospective teachers' understanding of collaboration and assessment of collaboration in modeling process even though the most common learning context in modeling activities are group work. Based on MOAA, learning context of modeling resembles professional practice, and prospective teachers' understanding of social learning and assessment context of modeling needs further studies.

Importance of Experience with Modeling & Incorporating in Instruction

The second theme is related to research which points to the importance of experience with modeling during teacher education. In one segment of the articles found, researchers analyzed prospective teachers' experiences with modeling, and in many cases, researchers

compared prospective teachers' views of models and modeling at the beginning and the end of a methods course (which sometimes included student teaching). One common finding was that many prospective teachers were not familiar with models and modeling at the beginning of the course. However, classroom modeling experiences enhanced prospective teachers' understandings about the roles of models and modeling, and prospective teachers were more articulate about scientific models (Crawford & Cullin, 2004) after receiving such instruction.

Windschitl and Thompson (2006) found that past investigative experiences influenced conceptual frameworks for prospective teachers as to what was recognized as a model and the ways models can be incorporated into inquiry. These studies asserted that it is important not only for prospective teachers to experience modeling in teacher preparation programs but also to have experience with models in pre-college level schooling or informal learning.

Kenyon et al. (2011) emphasized that prospective teachers must experience modeling practices in their methods courses, because engaging in modeling practices can promote the development of metamodeling knowledge (Schwarz & White, 2005) about models and modeling in addition to science content knowledge. In their teacher education courses, the authors engaged prospective teachers in modeling activities and taught them how to critique and adapt curriculum materials. This emphasis on experience with modeling practices was consistent with many other scholars' (Davis, 2006; Schwarz et al., 2008) ideas of the importance of incorporating modeling into science lessons. The theoretical frameworks of much of this work is based in experiential learning and embodied learning grounded in constructivist philosophy. In many of these studies, these frameworks are central to the rationale for prospective teachers to experience modeling to learn scientific practices. In particular for modeling practices, Windschitl et al. (2008) emphasized that it is important to situate learners through experiences with models and

modeling, such as learning and becoming comfortable with new meanings of words, symbols, images, or ideas within the context of embodied experiences.

Secondly, the researchers recognized prospective teachers' modeling practices as developing instructional tools in their classrooms (Kenyon et al., 2011; Ogan-Bekiroglu, 2006) and evaluation practices (Nelson & Davis, 2012). In many cases, scholars investigated both teachers' knowledge and their ideas about modeling practices in their instruction. Adams (2004) emphasized that the prospective teachers' experience with modeling needs to be incorporated in an instructional module to ensure the growth of knowledge of modeling across the span of several courses. He also addressed how the models of scientists need to be "near transferred" to models like the ones the students constructed. He wrote about this issue as follows: "for a kind of 'near transfer' that would be tied to models related to the ones the students constructed." (p. 37). Most importantly, Adams (2004) recognized that the importance of prospective teachers' views about roles of themselves in knowledge construction in modeling, and ultimately would influence their science teaching, their insight into "students' views of models and their more general views about whether they see themselves as producers or consumers of knowledge" (p. 37). This implies that when prospective teachers view students as knowledge producers rather than consumers, they would teach science with more student-centered approach. More authentic instruction and assessment of modeling, prospective teachers need to experience model creation and revision (Crawford & Cullin, 2004; Windschitl et al. 2008), then they can apply the knowledge of modeling process as a knowledge building tool (Schwarz et al., 2009) in their instruction, and the models can be assessed with rubrics.

In Kenyon et al.'s (2011) study, prospective teachers experienced a whole range of modeling processes regarding evaporation and condensation, then designed lessons and activities

that incorporated modeling. Windschitl & Thompson (2006) prompted prospective teachers' immersion in an investigation, such as observing live fish, posing their own questions, and collecting data. Prospective teachers were then required to do their own authentic inquiry project by building a model and transforming existing curriculum materials into more authentic investigations. Kim (2015) examined multimodal models for diverse populations and how prospective teachers became involved in their learning through their experiences with multimodal models (2D diagrams, 3D physical models, computer simulations, and gestures) based on an embodied learning approach. Scherr et al.'s (2013) research investigated how learners, engaged in an Energy Theater, during which they learned the difference between energy flow and matter flow and energy transformation. Their study used unique modeling activities, even though their participants were secondary in-service teachers who participated in Energy Theater professional development courses. The teachers became engaged in modeling electrons or energy flow by acting out the processes with their bodies, and the researchers analyzed their positions, movements, snapshots, and conversations through videotaping these exercises.

It is important to note that through experiencing modeling in a teacher education course, prospective teachers understand how to model, how to use models and modeling in their lessons, as well as the content they are modeling. This is also an important insight about learning science content with modeling practice at the same time (Manz, 2012). Prospective teachers' experience with multimodal models to understand a phenomenon from Kim's (2015) study resonated with Kamen's (1996) use of variety of models to assess student learning.

Prospective Teachers Struggle with Learning Models and Modeling

Researchers have found that prospective teachers are generally not familiar with models and modeling prior to formal instruction on the topic, and this is basis of the third theme.

Additionally, when prospective teachers learn about models and modeling in teacher preparation programs, they struggle. Danusso et al. (2010) investigated over 400 prospective teachers' knowledge about models and modeling over three years at two Italian universities. The authors noted that, after graduation, prospective teachers were still rather unskilled in and confused about models and modeling; in particular, prospective teachers had trouble differentiating between modeling and scientific methods, theory, and teaching methods. For example, prospective teachers may exhibit a limited view by saying, "a model's main components are the demonstration and the experiment," rather than explanations or predictions (p. 988). Also, Schwartz (2009) described prospective teachers' confusion about modeling and inquiry practices. Prospective teachers tended to view modeling through a more familiar lens like the scientific method; in addition, their understanding of modeling was constrained by their beliefs in the scientific method as the standard of scientific work (Kenyon et al., 2011; Windschitl & Thompson, 2006). Windschitl et al. (2008) tried to distinguish among models, theories, and scientific methods in their teacher preparation program to reduce this confusion.

In addition, most researchers used prospective lesson plans or unit plans as a data source. Most of the prospective teachers could incorporate modeling construction in their lesson plans, but they struggled to incorporate model evaluation and revision and metamodeling knowledge in their lessons (Kenyon et al., 2011). The authors also recognized a need to examine how this transfers into real school contexts. Windschitl et al. (2008) examined how prospective teachers adopted modeling practices in their own teaching during student teaching as well as in their methods course. They observed prospective teachers incorporating modeling in their own classrooms during the student teaching experiences (about 50%). However, they found that some prospective teachers consistently and explicitly utilized modeling in their lessons. Yet among

their research participants they found most of the other possible combinations of these two descriptors. Some prospective teachers consistently but inexplicitly used modeling in their lessons, some prospective teachers didn't use modeling, and some prospective teachers actually used modeling practices, but they didn't realize they were modeling practices.

Prospective Teachers' Understanding of Modeling with Technology

The forth theme brings in the use of technology with modeling. For modeling experiences, some scholars incorporated modeling experiences with modeling software (Daunso et al., 2010; Crawford & Cullin, 2004; Kim, 2015; Schwarz et al., 2007; Schwarz, 2009). In fact, in terms of the use of technology platforms (7 articles of 16 articles in our collection), the research findings showed mixed views. Some scholars agreed and were fascinated with the use of computer modeling tools (Valanides and Angeli, 2006). Valanides and Angeli's (2006) study also used Model-it as a computer modeling tool which engaged prospective teachers in rich modeling experiences in a relatively short time. Also, they addressed the positive effect on prospective teachers' learning in effectively scaffolding their first modeling experience and Model-it provided viability of the models based on the simulated outcomes.

However, sometimes, prospective teachers also struggled with the use of technology. Crawford and Cullin's (2004) study, the authors used software Model-it with prospective teachers in science methods course. Through this modeling tool, prospective teachers designed and built models based on collected data regarding the health of water in a stream. Then, they tested, revised and shared models. Crawford and Cullin (2004) found that model-building experiences with Model-it enhanced prospective teachers' understanding of the role of models and modeling. However, there was no significant progress in the prospective teachers' intentions to teach about models. Schwartz (2009) noted prospective teachers' difficulties applying

modeling-centered inquiry using technology tools, and in a previous study, Schwarz, Meyer and Sharma (2007) investigated the infusion of computer modeling and simulation in a 1-semester undergraduate elementary science methods course. Prospective teachers used computer modeling and simulation tools within their own science investigations, then explored, evaluated, and taught their peers about a particular modeling tool. The goals of this intervention were for prospective teachers to learn about and use modeling tools to develop their understanding of model-based inquiry and to learn about useful technology modeling tools. The results were positive.

Prospective teachers viewed using software modeling tool as a good teaching strategy. However, they concluded that prospective teachers desired fun, easy-to-use software with scientifically accurate information. For example, in Schwarz, Meyer and Sharma's (2007) study, one prospective teacher showed the benefits of using computer modeling for student engagement (i.e., game-type pieces), but another prospective teacher expressed disappointment with the software due to inaccurate information when s/he had built a cause and effect model using the computer. Also, this prospective teacher was concerned that students would believe false information. The concerns about inaccurate information that might arise through computer modeling clearly demonstrated teacher's beliefs without a preset algorithm, computers might not work accurately. Adams (2004) pointed out that when students were involved in creating computer representations in computer modeling software, sometimes they just focused on creating the representations rather than engaging with the ideas behind those representations. Thus, he suggested to that emphasis be placed on the ideas behind the models rather than model construction itself. Also, Adams (2004) recommended to provide concrete examples in the context of a specific issues than general and abstract questions for prospective teachers. There are few approaches for using computer modeling tools within the authentic assessment literature.

What Research Says about Prospective Teachers' Views of the Assessment of Modeling

Undeniably, the assessment of models and modeling has been under-studied at K-12 levels and in science teacher education, and this is the fifth and final theme. Namdar and Shen (2015) reviewed articles about modeling-oriented assessments within K-12 education from 1980 to 2013. According to their review, they identified 30 articles among the huge amount of modeling based instruction articles. However, in teacher education, in particular, prospective teachers' views or knowledge about the evaluation or assessment of models and modeling is rare. Nelson and Davis (2012), Kenyon et al. (2011), and Schwarz (2009) dealt with prospective teachers' understanding of model evaluation practices. Both Kenyon's et al. (2011) and Schwarz's (2009) studies discussed prospective teachers' struggling with incorporating model evaluation in their science lessons. However, Nelson and Davis (2012) investigated how prospective teachers evaluated students' scientific models and how prospective teachers' PCK, skills, and self-efficacy changed in regards to model evaluation. In fact, Nelson and Davis's (2012) study was the only article that explicitly focused on prospective teachers' ideas about model evaluation criteria on student-generated models. In this study, prospective teachers were required to assess student-generated models (two different diagrams) about evaporation and condensation in a solar still. Prospective teachers provided a verbal evaluation of the students' work and, then, reflected on the criteria used to evaluate the students' models. Nelson and Davis (2012) found that prospective teachers' understanding of scientific modeling increased, and they gained self-efficacy in evaluating student-generated models. The authors found that the elementary prospective teachers planned to assess student-generated models with these criteria; sense-making, communication, consistency with evidence, aesthetics and features, generativity, mechanism or process, terminology, the purpose of model, etc. Many criteria are overlapped

with Namdar & Shen's (2015) MOA criteria. For example, generativity, in Nelson and Davis's work, refers to model generalizability in Namdar and Shen. Model-based predictions, in Nelson and Davis, provides a conceptual frame that is similar to the coherence of a model in Namdar & Shen (2015). Except for the *purpose of model*, most criteria in Nelson and Davis's (2012) study are related to modeling product (PROD-) among Namdar & Shen's (2015) three dimensions. In Nelson and Davis's (2012) study, prospective teachers did not create criteria in assessment of modeling practice in modeling process. The prospective teachers were asked to talk about how to evaluate prepared student-generated models. Nelson and Davis's (2012) study implied the importance of prospective teachers' experience with evaluating models, as such they can learn what is a good model as well as how to teach and facilitate students' model evaluation practice.

Summary

The review of articles about modeling practices related to prospective teachers' learning generated five common themes:

- Most of the Research Focuses on Teachers' Knowledge about Modeling
- Importance of Experience with Modeling & Incorporating in Instruction
- Prospective Teachers Struggle with Learning Models and Modeling
- Prospective Teachers' Understanding of Modeling with Technology
- Few Studies Have Been Conducted on Prospective Teachers' Views of the Assessment of Modeling.

There are very few studies in prospective teachers' evaluation practice on student-generated models, modeling process, and meta-modeling knowledge of students in science education so far. Most importantly, there is need for research on whether teacher (pre- and in-service teachers) recognize MOA as authentic assessment based on essential characteristics of

authentic assessment, and how they view the benefits and limitations of MOA as authentic assessment. Ultimately these research findings will inform science teacher education.

Another feature among the modeling articles reviewed is that there was a lack of research on modeling in engineering/technology related to teacher education. Few studies about modeling in engineering design contexts in science education exist. However, modeling in design cycles is an important process, as there is an emphasis on science and engineering practices in the NGSS. In this review, we hope the MOA can be recognized and considered as authentic assessment by teacher educators and prospective teachers.

Connecting themes to MOAA

MOA, Authentic Assessment, and Teacher Education

From the literature of authentic assessment, insights about how prospective teachers learn to implement MOA as authentic assessment in science lessons are gained. Houtz & Quinn (2006) used an authentic assessment technique to evaluate development of science process skills of middle school students. They incorporated hands-on activities, laboratories, and model construction. In particular, in modeling activity, students were asked to construct a model of sugar molecule. The primary assessment goal was accuracy of model. Formative assessment and feedback were given to the students during active modeling practice. Subsequent summative assessment was conducted as observations by teacher participants during the students' presentation. Houtz & Quinn (2006) stressed that appropriate assessment instruments for the integrated evaluation of attitude, content knowledge, and process skills are not readily available. This study showed how to incorporate modeling in instruction and assessment as authentic

assessment as prospective teachers struggle with incorporating model evaluation (Kenyon et al., 2011).

Bouwma-Gearhart & Bouwma (2015) attempted to assess; 1) students' ability to construct and revise scientific models, 2) understanding of how to judge the strength of models, and 3) ability to communicate about all of these. The understanding of how to judge the strength of models is one of the meta-modeling knowledge, the knowledge of model evaluation. The authors reviewed with students what makes for the strongest scientific model building on the work of Cartier et al., (2001). The criteria used were: 1) empirically consistent with all data, 2) conceptually consistent (realistic), and 3) have predictive power during modeling activity. The high school students observed the common house cricket (*Acheta domesticus*) in a lab to explore the relationship natural and sexual selection. Based on the observed data, they proposed an explanatory model. Example questions for assessment were, 'Describe any revisions to your model of selection in terms of the relationship between natural and sexual selection', 'Evaluate the "strength" of your model. To what extent does your model meet the criteria for a strong scientific model?'. From the analysis of observations, survey and interviews, they found the high school students demonstrated growth in understanding of how science is done. Also, the students highly developed in argumentation for the strength of their model and recognized model evaluation is ultimately performed by a scientific community. Bouwma-Gearhart & Bouwma (2015) concluded,

While constructing robust, scientifically accepted conceptual models central to scientific disciplines, this modeling-based inquiry curriculum also fostered students' understanding of the processes of inquiry, collaboration, and communication regarding crosscutting

concepts in science via participation in communities akin to those of practicing scientists. (p. 132).

These authors' implementation of model-based inquiry with labs, model presentation, and collaboration was a very good example of how to incorporate MOA as authentic assessment in modeling instruction. Implementation of embedded assessment questions in the modeling process was a great example of the integration of instruction and assessment with authentic learning environment (lab, observation, constructing models, argumentation, presentation, etc.) similar to what scientists do. In terms of assessment criteria to assess students' understanding of model evaluation, they did not identify the creation of rubrics in the article, however, their work did demonstrate very well how to incorporate activities to engage students in the construction, revision, and evaluation of models in the modeling activity. In fact, these two articles of Bouwma-Gearhart & Bouwma (2015) and Houtz & Quinn (2006) are representative literature in integrated MOAA even though it is not related to prospective teacher education.

From our authentic assessment in K-12 science education, only two articles were related to online assessment system. Liu, Lee, & Linn's (2011) study used WISE (Web-based Inquiry Science Environment) in which students experience interactive visualizations, in-class experiments, collaborative learning. The WISE has embedded assessments and real-time feedback. In WISE, students interact with models that help make micro and macro scientific concepts visible and testable, which is the benefit of technology-enhanced modeling. Technology-enhanced modeling environment covers scenarios not feasible with physical labs in virtual computer labs. Through technology-enhanced modeling-oriented assessment (TMOA), teachers can assess students' conceptual understanding and complex phenomena through visualization as opposed to memorization or reading. Also, inquiry skills and modeling practices

can be assessed in virtual labs or interactive simulation (Kim, Namdar, & Shen, 2014). TMOA's automated or real-time feedback function as formative assessment for student learning. Chang & Chiu (2005) and Liu, Lee, & Linn's (2011) studies are online-based large scale assessments. They commonly tried to use multiple-choice items, open-ended or constructed-response items in assessment, but in the context of real-life situation to be more authentic assessment. We couldn't find prospective teachers' responses on large-scale assessment using technology-enhanced modeling, but prospective teachers' understanding of MOA in technology-enhanced learning environment needs to be studied in relation to their concerns on accurate information. In fact, 25 articles in MOA (total 30 articles) were TMOA in Namdar & Shen's (2015) study. In terms of the integration of instruction and assessment in authentic assessment, it is beneficial for students to get automated feedback or real-time feedback for their learning in computer modeling.

Tensions between Teacher Education and MOAA

By introducing MOA in science teacher education program, the integration of modeling-instruction and assessment can be promoted, and this integration extends and enhances teacher knowledge of models and modeling. More authentic MOA (which we have labeled MOAA) needs to be attempted and examined in science lessons with diverse assessment formats. In addition, the use of a variety of models for MOAA is one way to validate the learning outcomes as well as the reliability of MOAA.

Table 2.4 showed the linkages of MOAA and teacher education. These linkages exist as tensions between these two domains. From the review of MOAA in K-12 education and the review of prospective science teachers' understanding of modeling, we learned implications for how to prepare prospective science teachers to implement assessment of models and modeling in K-12 science classrooms.

In *Table 2.4*, we did not include the 30 MOA articles which were identified in Namdar & Shen's (2015) study. However, these articles provided insight into the characterization of MOA as a form of authentic assessment. The MOA research of Namdar & Shen (2015) focused on studies that attempted to assess student learning outcomes using modeling (criteria: models, modeling practices, and meta-modeling knowledge). Within the MOA research of Namdar & Shen (2015) exists the conceptual aspects of authentic assessment. And, our primary interest arose because studies that directly examined authentic assessment in science education could be applied to many formats, and one of the formats was a model.

Table 2.4 MOAA & Implications for Science Teacher Preparation

Themes	PSTs' Modeling	MOAA (K-12)	Implications for Science Teacher Preparation
Research Focused on Knowledge of Modeling of Prospective Teachers	Crawford & Cullin, 2004; Daunsso et al., 2010; Frede, 2008; Kim, 2015; Kenyon et al., 2011; Nelson & Davis, 2012; Ogan-Bekiroglu, 2006; Schwarz, 2009; Windschitl & Thompson, 2006	Bouwma-Gearhart & Bouwma (2015) Kamen (1996)	(1) PSTs need to learn about the significance of the integration of instruction and assessment. (2) PSTs need to understand MOAA task is to assess the integration of knowledge, skills, attitudes of modeling. For example, students develop content knowledge, modeling skills and communication processes through authentic assessment using modeling.
Importance of Experience with Modeling & Incorporating during Teacher Education Instruction	Crawford & Cullin, (2004), Windschitl and Thompson (2006), Kenyon et al. (2011) Windschitl et al. (2008), Adams (2004), Kenyon et al., 2011; Ogan-Bekiroglu, 2006, Nelson & Davis, 2012, Kim (2015)	Bouwma-Gearhart & Bouwma (2015) Kamen (1996)	(1) As a result of experience with modeling in teacher education courses, PSTs should understand how to create models, how to use models and modeling in their own instructional lessons. (2) PSTs gain insights of simultaneously learning science content while involved in modeling practice (Manz, 2012). (3) PSTs gain insight into the use of diverse forms of models to validly assess students' understanding.
Prospective Teachers Struggle with Learning Models and Modeling <ul style="list-style-type: none"> • PSTs' confusions on model and other constructs. • PSTs' struggling with incorporating model evaluation, revision, and meta-modeling 	Danusso et al. (2010), Schwartz (2009), Kenyon et al., (2011), Windschitl & Thompson, (2006), Windschitl et al. (2008)	Houtz & Quinn (2006) Bouwma-Gearhart & Bouwma (2015)	(1) PSTs need explicit learning about models/modeling as well as meta-modeling knowledge: i.e. by distinguishing scientific methods, demonstration, experiment, theories, or inquiry. (2) PSTs need to learn about possible criteria by introducing MOA <ul style="list-style-type: none"> a. Accuracy of model can be assessed (Houtz & Quinn, 2006)). b. Assessment of students' ability to construct and revise scientific models (Bouwma-Gearhart & Bouwma, 2015). Assessment of students' understanding of how to judge the strength of models (Bouwma-Gearhart & Bouwma, 2015). c. Ability to communicate about models (Bouwma-Gearhart & Bouwma, 2015). (3) PSTs need to learn about formative & summative

			assessment using models a. Formative assess can be conducted during modeling with valuable feedback. (Houtz & Quinn, 2006). b. Summative assessment can be conducted by teachers' observation on presentation (Houtz & Quinn, 2006)).
Prospective Teachers' Understanding of Modeling with Technology	Daunso et al., 2010; Crawford & Cullin, 2004; Kim, 2015; Schwarz et al., 2007; Schwarz, 2009, Valanides and Angeli (2006), Adams (2004)	Liu, Lee, & Linn (2011) Chang & Chiu (2005)	(1) PSTs need to learn about Technology-enhanced modeling oriented assessment tools and embedded forms of MOA. (2) PSTs need to learn about how at authentic assessment can be multiple-choice items or constructed-response items in online forms.
Prospective Teachers' Views of the Assessment of Modeling	Nelson and Davis (2012), Kenyon et al. (2011), and Schwarz (2009)	Namdar & Shen (2015) MOA	(1) Need for further research on PSTs' understanding of model evaluation, in particular, having a comprehensive picture of criteria in three areas: modeling product, practices, and meta-modeling knowledge. (2) PSTs need to learn about possible criteria for creating rubrics using MOA.

Table 2.4 is an attempt to show internal “tensions” that connect the five themes identified in the previous section with associated implications for science teacher education (as shown on the right side of the table). The tensions emerged from the research on PSTs’ understanding of modeling generated implications into prospective teacher education.

The first tension, ‘Research Focused on Knowledge of Modeling of Prospective Teachers,’ suggested that PSTs need to have an integrated view of modeling instruction and assessment. At the same time, PSTs need to understand a MOAA task is to assess the integration of knowledge, skills, attitudes of modeling.

The tension that arose from the second theme, ‘Importance of Experience with Modeling & Incorporating in Instruction’ are related to the limited experience and unfamiliarity of PSTs in modeling. This tension implies that PSTs need to experience in both modeling itself and instructional approaches to modeling in teacher education courses. As a result of experience with modeling in teacher preparation, PSTs should understand how to create models, how to use models and modeling in their own instructional lessons. Also, PSTs need to be aware that students are simultaneously learning science content while involved in modeling practice (Manz, 2012). In addition, PSTs should gain insight into the use of diverse forms of models to validly

assess students' understanding (Kim, 2015). These limited experiences and unfamiliarity in modeling is also connected to the third theme, PSTs' struggling with learning models and modeling.

The third theme, 'Prospective Teachers Struggle with Learning Models and Modeling' demonstrated many tensions for PSTs to implement models and modeling in their future classrooms. First tension is in PSTs' confusions on model and other constructs in their process of learning modeling which could cause confusions of future students otherwise PSTs understand and implement correctly. The second tension is in the struggling with incorporating model evaluation, revision, and meta-modeling in their future classrooms even though PSTs understand the importance and benefits of modeling. This tension implies the needs of development of a form of pedagogical content knowledge for prospective science teachers. With awareness of these tensions and from the review of MOAA, many implications were identified. First, PSTs need explicit learning about models and modeling as well as meta-modeling knowledge (i.e. by distinguishing scientific methods, demonstration, experiment, theories, or inquiry). Secondly, PSTs need to learn how to incorporate modeling in their lessons. In many cases, PSTs struggled with the corporation of model evaluation, model revision, and meta-modeling knowledge in science lessons. However, PSTs can understand how to evaluate student-generated models, how to guide students to construct and revise their models in teacher preparation courses. Also, PSTs can learn students can learn meta-modeling knowledge with explicit explanation of nature of models (e.g., teaching the changing nature of models in the process of model construction and revision). Third, PSTs need to learn how to use models as an assessment tool. PSTs can learn about possible criteria to incorporate model evaluation in their lessons. For example, PSTs can learn that accuracy of model can be assessed in models and modeling, or students' competency

to construct and revise models can be an assessment goal. Also, PSTs can learn about formative & summative assessment using models. Formative assessment can be conducted during modeling with valuable feedback or summative assessment can be conducted by teachers' observation on presentation (Houtz & Quinn, 2006).

In the fourth theme, 'Prospective Teachers' Understanding of Modeling with Technology', PSTs showed mixed ideas on technology. PSTs understand the benefits of technology-based modeling in motivation and engagement of students, at the same time, they questioned the accuracy of models' representations. This implies that PSTs need to understand forms and functions, and limitations of technology-enhanced modeling tools. Further PSTs need to be exposed the use of embedded forms of MOA in technology-enhanced modeling tools which can be authentic assessment in science education.

Similarly, in the last theme "Prospective Teachers Views of the Assessment of Modeling" there exist two tensions. The first is related to the issue of having a comprehensive picture of the criteria for evaluating models – product, practices and meta-modeling knowledge. This tension has a range of possible values for any given PST between the absence of a comprehensive view to a fully comprehensive view through which the PST can elaborate the three areas of models as described by the MOA framework. The second tension is related to the construction of rubrics and has a range of possible values between no knowledge of rubric creation and knowledge of how to create a multi-component rubric that evaluates all of the student-created model's components that are part of the instructional objective for lessons.

In this paper, we tried to examine and integrate the different research area, PSTs' understanding of modeling and MOAA (Modeling Oriented Authentic Assessment) to gain insights for teacher education. *Figure 7* illustrated the structure of this study.

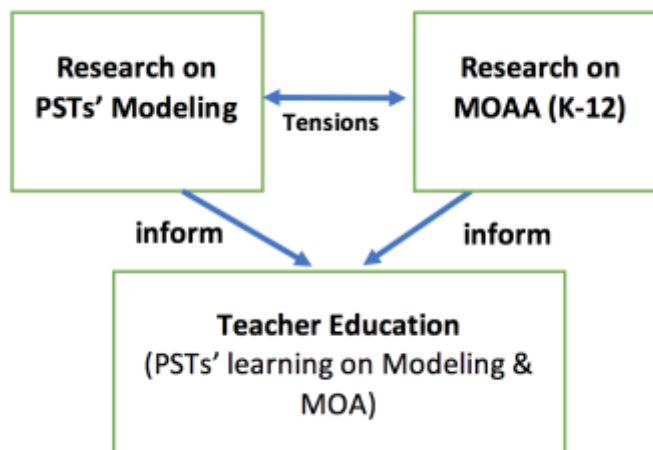


Figure 2.7 Relationship among constructs in this study

Implications

In the research reported here, we have reviewed the literature on Modeling-Oriented Assessment (MOA) and its linkages to authentic assessment of learning in the science classroom. In part 1, we reviewed how authentic assessment has been conducted in K-12 science education and how the essential characteristics of authentic assessment are matched with the characteristics of MOA. Based on the linkages, the MOAA (Modeling-Oriented Authentic Assessment) framework was presented. The Part II included a review of the literature related to prospective teachers' understanding of models and modeling in prospective science teacher preparation. Finally, we highlighted the implications of preparing prospective science teachers to implement modeling instruction and modeling-oriented assessment (MOA) in relation to the “tensions” generated between the themes from PSTs' understanding of modeling and MOAA.

This paper addressed, using the literature of teacher education, the problems that prospective teachers' limited experiences and understanding of models and modeling have when learning to teach. The tensions which emerged from the research on PSTs' understanding of

modeling generated implications as a basis for teaching assessment using modeling in science teacher education.

We learned that PSTs need to develop the knowledge of models and modeling with a comprehensive view: 1) modeling instruction and assessment need to be aligned, 2) MOAA tasks need to be integrated with knowledge, skills, attitudes of modeling as scientists' work. We also learned that PSTs need to experience in both modeling itself and instructional approaches to modeling in teacher education courses in order to enhance their knowledge of the use of modeling in their lessons. It was clear that there needs to be opportunities for PSTs' explicit learning about models and modeling, but also opportunities for learning how to evaluate student-generated models and modeling practices in teacher preparation courses. In this sense, we view the benefits of introducing MOA into prospective teacher preparation courses as one component of promoting a comprehensive view of modeling instruction and assessment. We also view the benefits of exposing PSTs to the variety of forms and functions of modeling, and limitations of technology-enhanced modeling tools. Each of these factors support a balanced view of instruction using modeling among many diverse forms of models. Finally, we learned that PSTs need support to implement MOA, having a comprehensive picture of the criteria for evaluating models – product, practices and meta-modeling knowledge in alignment with model-based instruction. PSTs can learn and be aware of possible criteria in implementing MOA to assess students' learning outcomes in science classrooms.

Conclusions

In this study, we examined the literature of PSTs' learning on models and modeling. We also reviewed the literature on authentic assessment using models/modeling, and compared this

literature to the MOA framework of Namdar & Shen (2015) and its identification of uses of models/modeling in science instruction and assessment in K-12 classroom settings. We addressed our observation that MOA has characteristics of authentic assessment, then, coined the new label for this new idea as MOAA (Modeling Oriented Authentic Assessment). From the research on PSTs' understanding of modeling, we identified "tensions" in prospective teachers' learning about modeling. From research on MOAA in K-12, we learned how to incorporate assessment of models/modeling in science classroom. All of these different bodies of research are connected and inform how to prepare our future teachers in learning modeling and MOA in their classroom, ultimately influence our future students' modeling practice.

We view this study adds to the body of knowledge on assessment of modeling as authentic assessment in relation to the established MOA framework (Namdar & Shen, 2015). We examined literature related to the two different constructs, compared MOA and authentic assessment and attempted to connect these two in an organic and informative way to provide insight about science teacher education in the context of prospective teachers' learning in modeling. In the review of literature, the synthesis put forward the idea that MOA is a form of authentic assessment in science education. We found MOA to be well matched to the essential characteristics of authentic assessment, which are: 1) reflection of real-professional life similar to the work that scientists do, 2) alignment with assessment and instruction, and 3) assessment of process as well as product.

Given the limited of instructional experience of prospective teachers as they transition to becoming future science teachers, their learning in modeling in teacher preparation is significant. However, if prospective teachers understand modeling as a real student-centered, active learning approach, as well as a knowledge building tool for students, they can incorporate modeling in

their instruction as well as add richness to the other aspects of their student-centered science instruction. In addition, modeling then becomes a tool to conduct assessment to provide feedback of student learning.

We have addressed the issues related to support prospective teachers' understanding of the assessment of modeling. Prospective teachers need to: 1) understand MOA as authentic assessment in science classrooms, 2) have a comprehensive view of the criteria for evaluating models – product, practices and meta-modeling knowledge, 3) learn how to evaluate student-generated models and modeling practices in alignment with modeling instruction, and 4) learn how to create a rubric that evaluates student-generated models in alignment with instructional objectives. Initiating prospective science teachers' learning about these aspects of modeling instruction is a powerful role for teacher education. Enactment of reform-based science teaching can follow from this first step much to the benefit of their future students.

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Appendix A. Literature review of the prospective teachers modeling practice

Articles	Research interest	Content area/Activity	Findings
Yenilmez Turkoglu, A. & Oztekin, C. (2016)	Understandings of PSTs possess about scientific models.	Biology, chemistry, and physics	(1) PSTs held fragmented views of models by having informed views in some aspects while having naïve views on others. (2) PSTs displayed a constructivist orientation and logical positivist views by believing that models should be close to the real phenomena that they represent. (3) PSTs generally conceptualized models' materialistic uses, yet they did not think much about their theoretical and conceptual uses.
Wilkerson, M. H.; Andrews, C.; Shaban, Y.; Laina, V.; Gravel, B. E. (2016)	(1) Pre-service teachers' understandings of scientific modeling. (2) Patterns in participating teachers' attention to content, representation, evaluation, and revision during technology-mediated activities and PD workshop.	Diverse science content for each group	(1) Group 1 focused on technology as a modeling tool, and their lesson included explicit opportunities for students to test and revise their simulations against evidence. (2) Groups 2 and 3 focused on technology as a way to share ideas. Their lesson plans emphasized the importance of critique and revising models based on feedback from peers. (3) Finally, Group 4 focused on technology as a way to show ideas, and emphasized the importance of students becoming comfortable sharing ideas with one another.
Kim (2015)	Teachers' use of multimodal models	(!) The relative motions of the sun and the earth, (2) Distance between sun and earth, (3) Use technology platforms: i.e., Stella and Facebook.	1. Promoting communication and emerging questions 2. Offering affordances through limitations 3. Explaining one concept involving multiple concepts for transformative and deep learning 4. Integrating teaching and learning experiences
Shen, J. & Jackson, D. F. (2013)	(1) kinds of geometric models will these participants use and how are they linked to the referents. (2) kind of measurement strategies participants employ for different models they choose. (3) How do the modeling and the measurement processes relate	Biology: tree measure using geometry modeling	(1) clarifying the object to be measured; (2) understanding the dynamic model-referent relationship (3) viewing indirect measurement as mathematical model-transformative modeling, the geometric model behind the "eyeball" method, (4) some PSTs didn't understand the underlying model and incorrectly interpreted the data; and (4) linking transformed models back to the referent-PSTs improved awareness of relative size in the metric system.
Nelson and Davis (2012)	PCK-SM: How to evaluate students' scientific models? How do PCK, skills, and self-efficacy for model evaluation change?	Solar still Evaluation of model criteria Consistency with empirical evidence Sense-making Communicative power	1. Four focal prospective teachers broadened their understanding of scientific modeling-based pedagogies and made gains in their self-efficacy for evaluating student-generated scientific models. 2. Prospective teachers can adopt criterion-based approaches to evaluating students' scientific models.
Kenyon, Davis, and Hug (2011)	*Development of modeling practice *Metamodeling knowledge	Evaporation/condensation 1. Constructing models 2. Revision of models 3. Lesson critique activity 4. Design lessons with modeling 5. Design activity for modeling 6. Using peer teaching, co-planning	1. Increased attention to model evaluation and revision 2. Developed appreciation for modeling in elementary classrooms 3. Attention to metamodeling knowledge and modeling process 4. Increase in thinking of models as sense-making tools 5. Incorporated model construction and use in their lessons 6. Struggle to incorporate model evaluation and revision, metamodeling knowledge in their lessons 7. See more connections between modeling and inquiry

Daunso, Testa, and Vicentini (2010)	Prospective teachers' knowledge about models and modeling (What is a model? What are components, functions, roles, and examples of models? Why use modeling activities in a classroom? etc.) The effect of an intervention	Group discussion after reading related articles and surveys, questionnaires, construction of conceptual maps Using modeling software and discussion Demonstration of experiments Demonstration of students' main difficulties about the concept of energy	1. Proposed experiment and virtual modeling activities to improve 2. prospective teachers' knowledge about models and modeling 3. Their proposed intervention may improve the knowledge of prospective math and physics teachers regarding models and modeling 4. The potential of the intervention retained an informed knowledge about models over a large time period 5. The design-trial-redesign approach is effective
Schwarz, C. V. (2009)	Professional knowledge and practices Views of effective science teaching and lesson-planning and productive science learning communities	(1) modeling and simulation tools for science teaching, (2) scientific inquiry regarding an instructional framework to develop modeling-centered inquiry, (3) curriculum materials analysis	1. Prospective teachers' confusion about modeling and inquiry practices and their difficulties applying modeling-centered inquiry using technology tools was indicated. 2. Indicated a need for a more coherent framework that was more central to their teaching practices 3. Prospective teachers struggled to assess meanings behind the criteria
Windschitl, Thompson, and Braaten (2008)	Understanding of the nature of and functions of models How participants' forms of reasoning and discourse change over time	Creation of conceptual models, Guided model-based inquiry on fish respiration, Exploring text resources on the role of models, Analyze authentic case studies of theory-Observe and critique exemplary MBI Final presentation	1. Compared to a previous study (2006), these participants were provided the scaffolding of the HPDD framework, and there are marked differences between the participants' performances over these two studies. 2. Prospective teachers incorporated modeling in their own classrooms while student teaching (about 50%).
Frede, V. (2008)	Understanding the content with modeling	Distance between sun and earth Refutational modeling (2D/3D)	Prospective teachers improved significantly when they had to refute their initial misconceptions practically.
Schwarz, C. V. & Gwekwerere, Y. N. (2007)			(1) PSTs used and adapted EIMA as an instructional framework, (2) PSTs learned how to plan inquiry-based lessons, (3) PSTs' use of models in their lesson plans and their ideas about models (PSTs also ended the course with a range of ideas about models), (4) PSTs changed their science teaching orientations.
Schwarz, Meyer, and Sharma (2007). Tech	Learning about and using modeling tools Learning about productive technology tools	Using computer modeling and simulation tools Conduct own science investigations; discussion about general technology issues Explored, evaluated, and taught their peers about a particular modeling tool	1. Prospective teachers expanded their vision of the software available and the role that software can play in science teaching to engage children in classroom inquiry. 2. Prospective teachers desired fun, easy-to-use software with scientifically accurate information within a clear, familiar learning task.
Windschitl and	The role of models Plans to use models	Immersed in investigation	1. Prospective teachers' understandings of scientific models positively influenced their plans for using

Thompson (2006)	Ability to create and use models	(observing live fish, posing their own questions, collecting data, and presenting the results to their peers) 11 weeks for the authentic inquiry project (transform a cookbook activity into an authentic investigation)	modeling activities with their own students. 2. Expert understanding of the nature and function of models is closely tied to the belief that it is important to teach about models as intellectual objects of critique and revision. 3. Using theoretical models as the basis for empirical investigations requires specific intellectual resources and reasoning strategies that are significantly more advanced than a generic understanding of scientific models. 4. Past investigative experiences contribute to durable conceptual frameworks for what is recognized as a model and the ways models can be incorporated into inquiry. 5. For most prospective teachers, the “scientific method” remains the dominant procedural framework for thinking about inquiry—to the exclusion of considering theoretical models as the basis for fruitful questions and for conceptual refinements after investigations.
Valanides, Nicos; Angeli, Charoula (2006) tech	1. Do preservice teachers’ models have a correct structure? 2. How “real” are preservice teachers’ scientific models? 3. What types of modeling experiences do preservice teachers infuse in their science lessons?	Growth of plants	The purpose of this study was to engage preservice elementary science teachers in a modeling experience with a computer modeling tool and, thereafter, study the effects of this experience on their abilities to construct viable scientific models and design a science lesson.
Crawford and Cullin (2004) Tech	Knowledge about what a model is, the purpose and use of modeling, and the changing nature of models Views and intensions of teaching models and modeling	Collecting data regarding the health of water in a stream Designing and Building models with <i>Model-it</i> Sharing findings Test models Revising models Presenting revised models	1. Model-building experiences enhanced prospective teachers’ understandings of the role of models and modeling. 2. No substantial progress was made in their intentions to teach about models. 3. How to build a model does not mean that learners can acknowledge the nature, components and functions of models
Van Driel, Jan H. & De Jong, Onno (2002)		Development of pedagogical content knowledge (PCK) in teacher education program.	(1) Changes in the preservice teachers' knowledge of difficulties associated with the learning of models and modeling, (2) Changes in the preservice teachers' knowledge of teaching activities aimed at promoting students' understanding of models and modeling, (3) Factors influencing the changes in the preservice teachers' knowledge.

CHAPTER 3

PROSPECTIVE TEACHERS' DEVELOPMENT OF KNOWLEDGE OF MODELING AS AN
INSTRUCTIONAL STRATEGY THROUGH ITS IMPLEMENTATION IN THE CONTEXT
OF PEER TEACHING²

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Abstract

This study examined secondary preservice science teachers' learning and enactment of instructional practices related to modeling. By teaching modeling activities to elementary science prospective teachers, the secondary prospective teachers exhibited behaviors that are analogous with pedagogical content knowledge (PCK). In addition, the prospective teachers recognized that modeling is an effective instructional strategy and has benefits for students related to the diverse forms of modeling.

Introduction

Globes, plastic human organs, a molecular model, a miniature solar system, and diagrams of plate tectonics...these models are usually easily accessible in almost every school science classroom or lab. Also, we might see Bohr's model of an atom, a water cycle model, and a food web model of interactions between organisms in any science textbook. But, what is a model? What role do models play in science and science learning? How do we incorporate models and modeling in science teaching for effective student learning?

In this paper, we try to shed light on aspects of prospective science teachers' knowledge and beliefs about modeling, explore implications of multimodality and ownership in designing and implementing modeling activities, and suggest how modeling can be implemented in science teacher preparation programs. In particular, we illustrate how prospective teachers' knowledge and beliefs about modeling as pedagogical content knowledge are embodied in their design and implementation of lessons using modeling.

Modeling is a core practice in the Scientific and Engineering Practices (SEP) included in the *Next Generation Science Standards* (NGSS). Scientists use modeling practice to describe,

explain, and/or predict scientific phenomena. In school science, students can construct, revise, and evaluate models to develop scientific knowledge and inquiry skills (Namdar & Shen, 2015; Schwarz et al., 2009). Modeling is recognized as an authentic scientific practice (Gilbert, 2004) rather than a practice grounded in a sequenced scientific method (Windschitl et al., 2008a). In addition, modeling is described as a cyclic and dynamic process (Lesh et al., 2000; Schwarz et al., 2009). Many studies have shown that instruction using models (i.e., Modeling-based Instruction) in science classrooms is beneficial in terms of active learning (NRC, 2012, Quellmalz et al. 2012), multiple representations (Shen & Confrey, 2007; Kim, 2015) and collaborative learning (NRC, 2012). Through modeling, students externalize their ideas clearly through multiple representations (Justi & van Driel, 2005; Kim, 2015; Schwarz et al., 2009; Shen & Confrey, 2007). In addition, modeling tasks can offer an authentic environment that mirrors what scientists do (Gilbert, 2004; Krajick & Merritt, 2012; Namdar & Shen, 2015; Penner et al., 1997). In this sense, students are able to learn science and how to do science, as well as to be assessed in authentic learning environments through modeling.

The NGSS suggests learning progressions in modeling and promotes the development of modeling skills from the early ages (NGSS Lead States, 2013). For example, young children can develop simple models to represent a proposed object or tool, such as concrete pictures and/or physical scale models. In later grades, students can develop and/or use multiple types of models with more abstract representations to support explanations, predict phenomena, analyze systems, and/or solve problems (NGSS Lead States, 2013; NRC, 2012). In addition, the NGSS (NRC, 2012) encompasses science and engineering practices, which are important in their relationships to the application of scientific knowledge in everyday life. The interplay of science and engineering is emphasized in that we are confronting challenges, such as generating sufficient

energy, preventing and treating diseases, maintaining supplies of clean water and food, and observing climate change (NRC, 2012).

Modeling is defined in many ways in science education. Schwarz et al. (2009) defined a model as “a representation that abstracts and simplifies a system by focusing on key features to explain and predict scientific phenomena” (p. 633). Prins et al. (2009) used the term model as a ‘structured representation’ of the essential characteristics of an idea, object, event, process or system. Shen (2006) defined a model as a human construct, with emphasis on the process of modeling. Shen & Confrey (2007) explained that models are used to describe, explain, predict, and communicate with others a referent such as a natural phenomenon, an event or an entity. Across all of these various conceptualizations of modeling, it is clear that scholars writing on this topic feel that to understand a phenomenon, learners need easier forms of explanations or multiple representations of the phenomenon of interest. In this study, a model is defined as a scientific tool that represents an object, an idea, an event, a process, and a system to describe, explain, predict, and communicate with others. Additionally, modeling is conceived of as a series of processes for constructing a model. This definition is somewhat general, but a broader definition of models/modeling in science, engineering (technology), and mathematics is meaningful, because classroom situations and contexts are integrated among those domains of STEM. In this paper, drawing on relevant literature, the term “modeling” is used in instructional settings in two different ways. First, it refers to a way of representing scientific ideas within an instructional setting. Students and teachers can use any representational forms, such as 2D drawings, diagrams, 3D models, computer simulations, or gestural models, to construct explanations of scientific phenomena and concepts. Second, it refers to a tool for engaging students in scientific activities. These “scientific activities” can be interpreted as practices similar

to what scientists do, including scientific practices, such as asking questions, developing models, carrying out investigations, constructing explanations, argumentations, and communicating with others. In this way, we can draw connections and reach a more holistic and integrated approach between learning scientific ideas through modeling and learning about modeling.

Framing the Study Theoretically

Modeling in Science Education

Halloun (2007) asserted that although modeling was originally linked to scientific theory and practice, it should be independently considered as an “effective pedagogical tool for helping students evolve into the realm of science and develop the sort of scientific literacy” (p. 653) in science education. Halloun (2007) expressed the need for aligning science curricula with the content and practice of science and engaging students in model-based reasoning and inquiry. He described the idea that model construction and deployment are not restricted to science, which has been supported by some cognitive scientists such as Gentner and Stevens (1983) and Giere (1992). Gilbert (2004) emphasized that models play equally important roles in science education, while agreeing that modeling is a pedagogical theory in science teaching and learning. Gilbert (2004) argued that students should understand the nature and significance of models in science as well as develop the capacity to produce, test, and evaluate models of phenomena. It is important to note that Gilbert (2004) viewed doing modeling as participating in the creativity and cultural value in science. In other words, students are able to engage in practices similar to what scientists do and experience the culture of scientific communities through modeling. In addition, Gilbert (2004) identified classes of models according to a model’s ontological status – *a mental model*, *expressed model*, *consensus model*, *scientific model*, *historical model*, *curricular model*, and

hybrid model – and, also, classified models’ modes as *concrete*, *verbal*, *symbolic*, *visual*, and *gestural*. In fact, many scholars use different terms referring to the same modes or types. For example, Lehrer and Schauble (2006) used a ‘physical microcosm’ instead of a ‘concrete model’. It is important to note that Gilbert (2004) identified a ‘curricular model,’ which is a simplified version of a scientific or historical model to aid in learning, due to an emphasis on modeling in science classrooms. Unlike other typologies, this curricular model is focused on science teaching and learning, so it could be less sophisticated than an expert’s model.

One striking research study on modeling is reported in Justi and Gilbert’s (2002) article, “Modelling, teachers' views on the nature of modelling, and implications for the education of modelers”. These authors clearly established the roles of modeling in science education:

(1) *to learn science*, students should come to know the natures, scope and limitations of major scientific models, (2) *to learn about science*, students should be able to appreciate the role of models in the accreditation and dissemination of the outcomes of scientific enquiry, and (3) *to learn how to do science*, students should be able to create, express and test their own models (p. 370).

In their study, Justi and Gilbert (2002) emphasized modeling as “acts” and explained how the act of modeling includes the formation of appropriate representations, building and use of mental models, learning of existing scientific models, modifying an existing model, or producing a personal model *de novo*. They suggested a series of cyclic processes of modeling, presenting a framework of “model of modeling” – decide on a purpose, select a source for the model or have experience, produce a mental model, express it in a mode of representation, conduct thought experiments, design and perform empirical tests, evaluate the results, and persuade others of its value with consideration of the scope and limitations of the model. They also pointed out the

core element in the model-construction process is scientific creativity and analogy on the relationship between the source and the target.

Halloun (2007) defined a model in science, as a “principal means that scientists represent, investigate, control, and impose order on physical systems and phenomena, and put together scientific theory coherently and corroborate it efficiently” (p. 653). In this sense, models “operate as a bridge” between scientific theory and “experienced reality” (Gilbert, 2004, p.116). Gilbert (2004) noted that scientists explain and/or predict scientific phenomena, objects, events, or a system through models in the processes of simplifications, abstractions, visualizations, and idealizations based on the analogous features between the model and what is being modeled.

Nelson & Davis (2012) addressed scientific models’ purposes within science learning situations and reported them to be understanding, communicating, and/or generating predictions about the system or phenomena. Their statement of purpose is in agreement with Gilbert & Boulter (2000) and Harrison & Treagust (2000). Nelson & Davis (2012) stated, “Teachers must help students understand not only factual and conceptual aspects of the science content involved, but also help students see how scientific models and modeling can be useful in developing and enhancing their own science content understandings.” (Nelson & Davis, 2012, p. 1933).

Manz (2012) also asserted the importance of the co-development of practice and conceptual understandings, and examined the relationship between practice and conceptual developments. Our view is more aligned with Manz’ (2012) view on modeling. We see the purpose of modeling in science education with an integrated interpretation, emphasizing both modeling practice for developing scientific understandings (Louca & Zacharia, 2012; Manz, 2012) and for developing modeling as an authentic scientific practice in science teaching (Crawford & Cullin, 2004; Gilbert, 2004; Henze, van Driel, & Verloop, 2008; Windschitl et al.

2008a). In terms of these two orientations to modeling, the different epistemic stances have led to a big difference in science teaching. Although there are epistemic differences, our perspective on modeling is intended to represent a more balanced view, a co-development of the conceptual understanding of content through modeling, scientific practice, and meta-modeling knowledge. When we think about modeling in school science, we need to consider science curriculum and levels of student development in its implementation in science lessons.

Conceptual Change and Modeling

For over three decades and right up until today, conceptual change theory as a means to examine student understanding is highly prevalent in modeling research in science education. Many researchers have noticed the process of modeling in one's learning as being similar to a change in the theories and models throughout the history of science. Halloun & Hestenes (1985) noted that students bring a loose mix of ideas about the universe and natural world into classrooms, or the so-called pre-Galilean paradigms. These pre-Galilean paradigms could include misconceptions, naïve conceptions, alternative conceptions, p-prims, etc. in theories about conceptual change. Students' pre-Galilean paradigms should have a 'Galilean leap' (Halloun, 2007) or a paradigm shift (Kuhn, 1962) to the scientific paradigms.

Some scholars view models as a conceptual system (Halloun, 2007) or a concept as a mental model (Shen, 2006) to explain students' conceptual change through modeling. The basic idea of modeling in conceptual change is that new models may conflict with students' pre-existing intuitive models (preconceptions), which need to change, and modeling is a strategy to foster that conceptual change. In this view, models and modeling are considered as evidence of students' mental models. Clement (2000) described learning as a process toward a *target model* from both students' alternative conceptions/models and useful conceptions/models. These two

types of preconceptions play important roles as ‘anchoring conceptions’ in developing a new model. The learning processes can take place by *intermediated models*, which function as partial models in developing the *target model*. Clement explained how this *target model* could be less sophisticated than the *expert consensus model* currently accepted by scientists (p. 1042-1043). *The target model* is more like a learning goal and a curricular model as Gilbert (2004) identified.

Gobert (2000) conducted research with 47 fifth graders (40 were group tested and seven individually interviewed) on their use of modeling in formal classroom science instruction. Specifically the students were reading a text describing plate tectonics. Gobert (2000) used student-generated diagrams as evidence and reflections of their mental models and, also, recommended drawings along with student-generated explanations. After reading the text, students were prompted to draw their mental models. These post-text assessments occurred four times over the course of the study. The examples of the prompts included ‘drawing a picture of the different layers inside the earth’ or ‘movement in the different layers of the earth.’ Then, the students who were interviewed were offered tutoring to promote model revision based on their initial models. In her quantitative analysis, the diagram group outperformed the summary group during the reading of the text. And, in her qualitative analysis on diagrams with written explanations, Gobert (2000) found students started with a simple spatial model, but even fifth grade students could gradually construct mental models of complex causal and dynamic models. In many conceptual change studies, researchers mainly compared, both quantitatively and qualitatively, a student’s model pre- and post-instruction or how a student’s model changed over time, viewing the model’s transformation as a change in concepts. However, most research was focused on students’ understanding of scientific concepts and learning outcomes using modeling, not on modeling practices such as the modeling process or the nature of models.

Nature of Science (NOS) and Modeling

If a student is unaware that a DNA double helix picture in a textbook is a scientific model, can the student have an in-depth knowledge of cell division or protein synthesis? This question resonates with how important students' understanding of the nature of models and modeling is to science learning.

Schwarz et al. (2009) emphasized that “modeling is a core practice in science and a central part of scientific literacy” (p. 632). Some scholars have expressed the importance of engaging students in authentic scientific practices, through modeling, which allows students to experience the dynamic and ongoing nature of science (Wu, 2010). Because modeling is one of the activities of science (inquiry) and an act of building knowledge, it has inextricable connections with the epistemology of science, how scientific knowledge is constructed (NOS). White and Frederickson (1998) suggested an inquiry cycle, and modeling is one of the processes of that inquiry cycle (Figure. 1). In the context of the nature of science (NOS), since scientific knowledge is subjective, theory-laden, and socially, culturally, and politically constructed (Longino, 1990; Haraway, 1996; Harding, 1992), modeling needs to be understood as a human act of knowledge-building. Therefore, it is important to emphasize how models and modeling contribute to building scientific knowledge and the nature and purpose of models and modeling. Indeed, in modeling literature related to NOS, the main foci are students' understanding of the representational nature of models, the changing nature of models, and the multiplicity of models (Treagust et al., 2002).

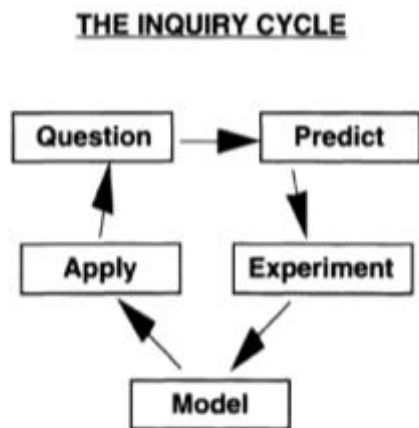


Figure 3.1 A model of the scientific inquiry process
(White & Frederickson, 1998)

Schwartz et al. (2009) were interested in the learning progression focused on the practice of scientific modeling, rather than on how particular ideas are developed. These authors argued that students need to understand how and why models are used and the strengths and limitations of them. They referred to this knowledge as metamodeling knowledge (Schwarz & White, 2005). The authors agreed that metamodeling is a kind of understanding about the nature of science (NOS) (Lederman, 2007), and modeling practice and metamodeling knowledge should not be taught separately. In their study, they investigated fifth and sixth grade students from several elementary and middle schools. The researchers designed a six-week unit for fifth graders about modeling evaporation and condensation phenomena using a solar still [distillation] device. The fifth graders engaged in modeling practices such as constructing, evaluating, revising, and using models to explain how the solar still worked and how evaporation and condensation occurred. Students' models were diagrams with written descriptions of the phenomenon. The fifth graders had metamodeling conversations (e.g. how they evaluate models) when they were comparing and contrasting different models for the process. Schwarz et al. (2009) indicated that elementary students shifted from drawing illustrative pictures to developing more abstract explanatory

diagrams, including invisible mechanisms, when constructing models. Also, some elementary students used their models to explain related phenomena when they were prompted to do so. For sixth grade students, the researchers designed a six-week unit of chemistry about a particle view of matter, and a six-week unit of physics about how the interaction of light, physical objects, and a sensor (our eyes) allows us to see objects. Three focus groups among the sixth grade students were enlisted from different classrooms learning the physics and chemistry units taught by the same teacher, and the researchers interviewed the focus groups (using pre- and post-interviews).

Related to middle school students' understanding of modeling, this study revealed that many students recognized models as communicating explanations to others (e.g., student responses like 'show what you're talking about' or 'explain to the others'). Interestingly, initially, these students considered models as a type of science answer, so they thought that models must be identical to the information provided in the textbook or by their teachers. However, at the end of the unit, students viewed their models as showing multiple aspects of a phenomena to be explained. Finally, these sixth graders revised their models to improve their communicative skills and included new information learned from their experiments.

Embodied Learning Approaches to Modeling

Modeling has been studied as an instructional strategy with an emphasis on the cognitive aspect of science learning (Clement, 2000; Justi & Gilbert, 2002). Within the perspectives of the nature of science (NOS) and inquiry, modeling has emphasized the benefits of critical thinking and inquiry skills, learning meta-modeling knowledge, and the nature of modeling. Recently, given the importance of multiple representations for diverse populations, the area of modeling research is broadening to incorporate the embodied cognition approach. Embodied cognition

concerns both individuals' rational decision-making and embodied engagement in the meaning-making process (Lemke, 2004).

Embodied learning (cognition) is a view that people learn and make sense of the world using their bodies and bodily activities, not just from thinking processes of the mind. In other words, bodily activities influence one's cognition (Hull & Nelson, 2005). In psychology, most research interests included mental or cognitive processes, which are identifiable and analyzable; however, embodiment plays an integral role in how one perceives oneself, other people, and the environment (Stolz, 2015). There has been a separation between the mind and body in school curriculum. This is the reason why content and subject matter have been privileged over practice for a long time. In education, embodied learning pursues being a 'whole person' and promotes holistic experiences and hands-on learning. Kucukozer et al. (2009) asserted that learners' bodily embodiment facilitates their motivation and interests as well as conceptual learning.

Roth and Lawless (2002) discussed science as a culture. They asserted, "science is a form of culture with its own creeds, language, material practices, perceptions, theories, and beliefs" (p. 368). Scientists' manipulations, sensing, and gestures play important roles in scientific laboratory talk and scientific language (Roth & Lawless, 2002). This idea of understanding science as culture is consistent with Longino's (1990) argument. Longino (1990) examined how scientific knowledge is socially and culturally constructed through observing the lives of high-energy physicists in her ethnography, *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry*. Therefore, it may be regarded that scientific knowledge is constructed based on funds of knowledge, which are embodied in the scientific culture. Recently, researchers have studied multimodal models in science teaching and learning for diverse learners. Lemke (2004) stated that language and discourse are embedded in practices and need to

be understood in contexts. Since language is used with other modes of representations, scientific communication and scientific literacy must be considered fundamentally multimodal (Lemke, 2004); this multimodality includes various modes of scientific descriptions, such as diagrams, pictures, graphs, charts, mathematical expressions, in addition to speech, images, gestures, and sounds. All of these forms of multimodal models are embodied learning tools that stem from students' lived experiences. Researchers have recently been studying each of the various modes of modeling, such as 2D drawing, 3D concrete model, gestures, 3D computer modeling, etc. It seems that how students perceive a phenomenon is embodied in their modeling practices as multimodal models. In this sense, modeling is the act of representing a target (phenomenon or system), and learners' perceptions from their lived experiences are embodied in the representation. In an embodied learning approach, it is important to provide students with embodied experiences to construct models.

Scherr et al. (2013) investigated how learners engaged in an Energy Theater to learn the difference between energy flow and matter flow and energy transformation. Participants in the study were secondary teachers who participated in an Energy Theater professional development courses. An Energy Theater is designed with social (collaboration) and embodied (participation with their bodies) learning activities. The authors explained that teachers were "constructing meaning by means of body placement, orientation, gesture, and other bodily actions" (p. 3). Participants were required to act like electrons or currents to model energy and matter flows and mechanisms of energy transformation. They observed and video-taped participants' changes in speech, behavior, and embodied interactions with each other. With an interpretive video analysis, they identified some specific concepts and episodes in which learners engaged. For example, two

participants, Ronald and Toni, engaged in a dramatic embodied action to model energy dynamics:

Ronald simultaneously walks and gestures to model the outward movement of energy along with the persistence of current around the circuit. Toni grabs two other participants to physically recruit them into her enacted model of an electron as a packet of three energy units that travel together, then transform and separate. (p. 9)

Scherr and colleagues (2013) described participants' embodied actions and layouts of their positions and movements, snapshots, and conversations. Through the teachers' conversations, the authors found that the learners engaged in productive discussions to understand energy concepts through these collective efforts. Their argumentation, persuasion and negotiation contributed to their construction of energy models. Also, the authors argued that the Energy Theater and its modeling practices supported conceptual engagement and provided a generative basis for energy instruction for diverse learners through embodied actions.

Modeling and the Nature of Knowing in Science Education

Manz (2012) suggested that science teachers use modeling activities as an instructional practice to teach scientific concepts, describing them as powerful tools for helping students engage in deeper conceptual understandings that take into account analogical reasoning between the target phenomena and models. This is one of the reasons why modeling research has been plentiful within the larger body of conceptual change research in science education. Many modeling activities in school science are mainly carried out for teaching scientific concepts. Students use different types of knowledge and cognitive strategies in modeling practices (Schwarz et al., 2009). Thus, modeling practice is considered a knowledge-building tool in science learning, since it is a way of understanding scientific concepts (Schwarz et al., 2009).

Many books and scholarly articles support models and modeling as a way of effective teaching and learning in science instruction for all ages (Gilbert & Boutler, 2000; Gobert, 2000; Louca & Zacharia, 2012; Shen, Lei, Chang, & Namdar, 2014; White & Frederiksen, 1998; NGSS Lead States, 2013).

On the other hand, many science educators consider modeling an integral scientific practice based on the constructivist epistemic stance. The constructivist perspective views the nature of science (NOS) as a tentative entity. Windschitl et al. (2008a) asserted that for 100 years, the scientific method (TSM) was overemphasized and dominated the scientific community, as well as science education. These authors emphasized model-based inquiry as an authentic form of inquiry for science and school science based on its epistemic issues with scientific knowledge. They suggested essential epistemic issues are *testability, conjecture, explanation, principled revision, and generativity*. They asserted that rather than representing scientific process as sequenced scientific methods, constructing and revising models to explain and predict scientific phenomena was more authentic when it comes to what scientists do. Henze, van Driel, and Verloop (2008) examined experienced teachers' development of Pedagogical Content Knowledge (PCK) for a specific topic, 'Models of the Solar System and the Universe.' The authors classified the two different types of PCK developed in different ways, comparing two different epistemologies (positivist vs. relativist) between the two teachers. The type A teacher (positivist view) was interested mainly in the model's content, but the type B teacher was concerned with the model's content, the model's production, and thinking about the nature of models (relativist view). These two main epistemic stances reflect two different orientations in the understanding and practicing of modeling. Henze, van Driel, and Verloop (2008)'s study

implies that these two different epistemologies have relationships with the development of different types of PCK on modeling.

Pedagogical Content Knowledge (PCK)

Pedagogical content knowledge (PCK) is the unique knowledge about teaching possessed by expert teachers (Cochran, 1997; Shulman, 1987). PCK is the amalgam of content and pedagogy, and encompasses teachers' understanding and enactment of teaching (Park & Oliver, 2008). PCK is embodied in a teacher's teaching in an integrated way of understanding, what teachers know about particular topics, how to organize and represent the topics, and how to help students understand specific subject matter (Shulman, 1987; Magnusson et al., 1999). In other words, teachers need to be able to transform their knowledge of subject matter into the classroom context (Carter, 1990).

There are many models that have conceptualized PCK. Some of these models present components of PCK: (e.g., Grossman, 1990; Tamir, 1998; Magnusson et al., 1999, and Park & Oliver, 2008, etc). These scholars modified Shulman's concept (1986, 1987) by empirical evidence or researchers' beliefs (Kind, 2009; Park & Chen, 2012). There are many overlaps with respect to the essential components of PCK among scholars. Based on the work of Grossman (1990) and Tamir (1988), Magnusson et al. (1999) suggested a refined model of PCK for science teaching with identification of five components: "(1) orientations toward science teaching, (2) knowledge and beliefs about science curriculum, (3) knowledge and beliefs about student understanding of specific science topics, (4) knowledge and beliefs about assessment in science, and (5) knowledge and beliefs about instructional strategies for teaching science" (p. 97). Park & Oliver (2008) proposed a pentagon model, mainly drawn from Magnusson et al. (1999) five components. The pentagon model paid attention to the integration and coherence among the five

PCK components (Park & Chen, 2012). In this study, we employed Park & Oliver (2008)'s model of PCK as an analytic tool due to its emphasis on the integration among five components.

Summary

In this section, we reviewed how modeling research has been carried out in science education. Many scholars have emphasized that models play an equally important role in science education as it does in science (Halloun, 2007; Gilbert, 2004; Justi & Gilbert, 2002). Modeling is in many ways a pedagogical theory in science teaching as well as for learning for the development of scientific literacy (Halloun, 2007). Modeling can be used in science instruction to accomplish a wide range of goals including: helping students to learn science, helping students to learn about science, and helping students to do science (Justi & Gilbert, 2002). In science education, modeling research has been conducted in terms of three main orientations: conceptual change, nature of science (NOS), and embodied learning. Scholars have paid attention to how the process of modeling as conducted by learners is similar to changes in theories and models in the history of science. The combination of these scholarly efforts has helped to explain students' conceptual change through modeling (Halloun, 2007; Shen, 2006). Modelling is a knowledge-building tool for science learners (Schwarz et al., 2009) just as models and modeling contribute to building scientific knowledge in scientific communities. Understanding how and why models are used and the strengths and limitations of models should not be taught separately with models and modeling (Schwarz & White, 2005). Modeling research has been broadened to incorporate the embodied cognition which emphasizes bodily activities and a holistic view of learning. Bodily activities influence one's cognition (Hull & Nelson, 2005) and facilitate motivation, interests, and conceptual learning (Kucukozer et al., 2009). Modeling is

considered as an integral scientific practice grounded in the constructivist epistemic stance. Finally, it is important to note that teachers' epistemologies have a significant impact on their classroom modeling practice, and ultimately on student learning through modeling (Henze, van Driel, and Verloop, 2008).

Context of the Study

This qualitative case study was conducted at a US southeastern state university during the 2015 – 2016 academic year. The research participants were secondary science prospective teachers who were taking a secondary science methods course as part of their science education degree and certification program. For most students, this course was part of the last year of their program. The prospective teachers were involved in school-based practicums, so they had started to learn how schools function, how to interact with secondary students and how to teach science in a classroom setting with students. The curriculum of the secondary science methods course covered major learning theories, inquiry based learning, science standards, such as the NGSS and Georgia Performance Standards (GPS), the design of lesson plans as well as assessments. In this methods course, there was a diverse group of students in terms of majors (physics, chemistry, earth science, and biology). A majority of these students had a science emphasis in biology. There were approximately equal numbers of male and female students as well as numbers of students enrolled in master's or undergraduate programs. In the fall of 2015, the secondary science methods course emphasized modeling practice among eight scientific and engineering practices. The prospective teachers were asked to create an assessment rubric using modeling in relation to their instruction using modeling. They created unit plans in their content area in alignment with three-dimensional teaching as suggested in the NGSS. Thus the unit plans were

developed to teach disciplinary core ideas, scientific and engineering practices, and cross-cutting concepts. In their unit plans, the prospective teachers were asked to include lessons and assessments using modeling. Prior to creating the modeling assessment rubric, the prospective teachers in this class had learned about modeling practice and experienced modeling firsthand, through experiences which included modeling-based inquiry, modeling-based reasoning, and modeling practice in science and engineering as described in the NGSS. Also, the prospective teachers had an opportunity to discuss important criteria for the design of modeling-based assessment. Among this group of prospective teachers, five students volunteered as primary participants for the study. Data sources for the study included lesson plans, video-recordings of mini-lessons, and semi-structured interviews (post-interviews are done with photo-elicitation).

Procedures of the Study

It is important for students to have opportunities to represent their scientific ideas to explain natural phenomena, in addition to experiencing firsthand the modeling process when constructing and revising their own models in science lessons, similar to how scientists use modeling. Thus, it is essential for science teachers to recognize modeling as an important practice and try to implement it in their teaching. In this study we examined prospective teachers' instructional approaches to modeling through their teaching implementation in the context of peer teaching. In addition, we investigated what they learned about modeling practice in instructional settings and their knowledge about how modeling practice can be accomplished in science classrooms. In this paper, we describe an implementation of modeling practice by prospective secondary science teachers. The modeling implementation was designed to examine the prospective secondary teachers' understanding of modeling and their enactment of

knowledge of modeling. In particular, these prospective teachers designed and implemented a mini-lesson to introduce unfamiliar peer groups of prospective elementary teachers to modeling practice. This peer teaching context was created to help the prospective teachers explicate their knowledge of modeling. This peer teaching not only served to assess prospective teacher participants' learning experiences with modeling, but was also an opportunity to express the prospective teachers' PCK of modeling. In fact, the initial plan was for the prospective secondary teachers to peer teach prospective secondary teachers in another methods course, but the course was cancelled on short notice. So, we adjusted the plan to provide the prospective teachers with an opportunity to teach in a methods course of prospective elementary teachers. Our goal was to examine the prospective secondary teacher participants' knowledge about modeling and their enactment of this knowledge in lesson designs and implementations in a similar context of teaching learners who are new to modeling practice. Even though the levels of learners (elementary and secondary) that these prospective teachers will teach in the future are different, we believed it was valuable to investigate the secondary prospective teachers' knowledge of modeling in a real teaching context. We assumed that their PCK about modeling, in particular, the knowledge of instructional strategies and student responses to their modeling activities, could be generated by experiencing teaching with modeling.

By examining the prospective teachers' implementation of modeling, our research addressed the following questions:

RQ1) What instructional knowledge do prospective secondary science teachers develop while designing and implementing modeling instruction during their methods and practicum coursework?

RQ2) What characteristics of pedagogical content knowledge (PCK) on modeling as an

instructional strategy do prospective secondary science teachers demonstrate?

In this paper, we describe how the prospective secondary science teachers designed and implemented their modeling lessons centered around specific topics and what they learned from the modeling implementation about instructional strategies for modeling practice. All five of the prospective teacher participants (Allis, Chris, Denise, Jodice, and Shannon; pseudonyms) in this study recognized modeling as a reform-based and ambitious practice relevant to their science teaching. Among the five participants, we highlight and contrast their pedagogical approaches and decision-making towards this instructional activity of using modeling.

At the beginning of semester, the prospective teachers were generally not familiar with modeling in accordance with what many previous studies have also found (Justi & Gilbert, 2002; van Driel & Verloop, 2002; Kenyon et al., 2011). As they experienced the modeling activities and modeling assessment in their science methods course, the prospective teachers became familiar with modeling-based instruction, and most of them expressed a willingness to use models/modeling as an instructional strategy and assessment tool in their future science teaching, a finding inconsistent with Crawford and Cullin's (2004) study. In the teaching context, the fact that the prospective secondary teachers didn't know the learners, prospective elementary teachers, gave them incentive to be more prepared and to recognize the need to articulate what modeling is for their audience. Each group of prospective secondary teachers presented a modeling activity to demonstrate how to incorporate modeling in science teaching and explained how student learning can be assessed through modeling. However, in these modeling implementations, there was no attempt to plan to teach the nature of models/modeling itself (meta-modeling knowledge) to elementary prospective teachers.

Each group of presenters consisted of two to four prospective secondary teachers. There were six different groups of prospective elementary teachers participating in these modeling mini-lessons. Each group of prospective secondary teachers planned a mini-lesson using modeling to teach a specific topic. Each group was given about 20 minutes for conducting the mini-lesson. In general, each group introduced modeling briefly and then engaged the elementary teachers in their modeling activity. They explained why and how their modeling activity could be incorporated with specific topics.

The five research participants were randomly assigned to separate groups for the presentations. First, each group of presenters decided on the science topic they would teach through a modeling activity. When they planned their lessons, the prospective secondary teachers were encouraged to consider the goals of the lesson that they would implement with the prospective elementary teachers and design a mini-lesson as an example of modeling-based instruction. Second, the prospective secondary teachers were expected to address the elementary science standards in the NGSS and GPS so that the mini-lessons aligned with the topics and learning goals. Third, the prospective teachers were encouraged to seek out related information (e.i. supplementary contents, possible activities and materials, etc.) about the topic they would be presenting and incorporate it into the design of their mini-lesson with an appropriate modeling activity. The topics selected for presentation were blood flow (blood pressure), wind speed (creating an anemometer), “Got any change?” (change in water phases), modeling energy with marbles (potential and kinetic energy), the rock cycle, and plant defenses. Each group prepared a worksheet or data sheet and a hands-on activity for the modeling-based instruction. The learners, the prospective elementary teachers, were asked to give feedback on each group’s mini-lesson and presentation. The instructor created a template containing a rubric to assist the elementary

teachers in providing feedback to the secondary teachers. The prospective elementary teachers were given the rubric ahead of the mini-lessons so that they could give feedback immediately. Each prospective elementary teacher gave feedback to each of the groups. After the implementation of the modeling activities, the five primary research participants also received the feedback for their own learning as did other classmates. The feedback form was a Likert scale evaluation form with comments about each group's presentation (e.i. clarity of demonstration, engagement, strengths and weaknesses of the modeling activities). The feedback was generated by the elementary prospective teachers and the course instructor arranged them as one document for each group. These five participants were interviewed after receiving all feedback. This feedback form was not included as a data source; rather this feedback was considered as one of the prospective teachers' learning experiences on modeling-based instruction. *Table 3.1* illustrates the five prospective teachers' background along with their modeling implementation topics.

Table 3.1 Participants background and modeling implementation topics

	Chris	Allis	Shannon	Denise	Jodice
Major	Biology	Biology	Biology	Chemistry	Biology
MAT/ BSED	MAT	BSED	BSED	MAT	MAT
Gender	male	female	Female	female	Male
Modeling implementation topic	Blood pressure	Plant defenses	Weather station	Got a change? (phase change)	Potential & kinetic energy
Forms of modeling	Lab activity	Physical models	Physical models	Gesture game	Gesture game Equations, graphs

Research Methods

This study utilized a qualitative case study approach. Patton (2002) explained how the purpose of a case study is to examine a phenomenon of interest by examining a case

comprehensively, systematically, and in-depth. A case study is used to investigate a phenomenon empirically in depth and within real-life contexts (Yin, 2009). Merriam (2009) stated, “case study plays an important role in advancing a field’s knowledge base” (p. 51). It is asserted that having a thorough knowledge of particulars is a form of generalization, “*naturalistic generalization*,” which is developed within a person as a product of experience (Stake, 1978; Stake & Trumbull, 1982; Stake, 1998). This naturalistic generalization process is described in this way:

The reader comes to know some things told, as if he or she had experienced them. Enduring meanings come from encounter, and are modified and reinforced by repeated encounter...In a social process, together they bend, spin, consolidate, and enrich their understandings. We come to know what has happened partly in terms of what others reveal as their experience... Knowledge is socially constructed... and thus case study researchers assist readers in the construction of knowledge. (Stake, 1998, p. 94-95)

Accepting that not every phenomenon can be explained by universality and valuing particulars are significant viewpoints to understanding how knowledge is constructed. Stake’s (1998) argument about the value of particulars is consistent with Simons (1996). Simons (1996) described that “by studying the uniqueness of the particular, we come to understand the universal” (p. 4). Considering beliefs about universality, however, Flyvbjerg (2011) made the point that, even in natural science, theories are disproved by a single experiment rather than requiring the observation of all possibilities and events of the phenomenon. Therefore, understanding particulars more deeply and accepting the value of particulars as contributing to the understanding of human experiences make up the essence of a case study. In other words, the way of knowing by case studies is to establish the value of each case, providing a rich portrayal

of a single case, as such aims to add to knowledge of a specific topic (Simon, 2009). By examining and interpreting a case in-depth through diverse lenses, a case study is broadening our understandings about a phenomenon of interest (Baxter & Jack, 2008).

All prospective teachers in the course were exposed to the same modeling activities, but each case is different depending on the prospective teachers' lived experiences, schoolings, motivations, practicum sites, and images of modeling. Therefore, this case study was intended to generate understanding of how prospective teachers learned about models and modeling, and how they designed and implemented their own modeling instructions with different experiences, context, and situations in-depth. In addition, in this study, each individual prospective teacher was a case, a unique exemplar for giving insights into prospective teachers' knowledge and experiences about modeling. Kagan (1992) stated, "A teacher's professional growth appears to be an inherently private affair, self defined and self directed." (p.78). For this reason, we examined individual cases even though participants' learning experiences and implementation of lessons on modeling consisted of both individual and group activities. We wanted to understand individual prospective science teachers' preparation for professional growth in teacher knowledge of modeling.

In light of the case study methods used in this study, we describe three participants' approaches as representative toward their learning about modeling and modeling implementation in the context of peer teaching. Primary data sources included the pre- and post- interview data, and video recordings of the mini-lesson modeling implementation with the elementary prospective teachers. Lesson plans and worksheets for the mini-lessons were secondary data sources. We triangulated the consistency between multiple data sources to increase the trustworthiness in and credibility of the findings (Lincoln and Guba, 1985).

Data Analysis

The data was analyzed using constant comparative method (Charmaz, 2011). Grounded theory is a systematic analysis method with emphasis on the inductive approach to data. In other words, grounded theory is a data-driven approach, not leaning on a pre-existing theory (Corbin & Strauss, 2008). In grounded theory, after collecting data, researchers follow the general steps: 1) generate codes from the data, 2) categorize each code to create concepts, 3) categorize the concepts, and 4) generate themes (Corbin & Strauss, 2008). Therefore, in general, the analytic steps are summarized codes, concepts, categories, and theory. Glaser (1965) suggested constant comparative method as an approach to analyzing qualitative data in grounded theory through a process of constantly comparing incidents applicable to each category, then integrating categories and their properties. The data analysis of constant comparative method is an interactive process (Charmaz, 2000; Glaser & Strauss, 1967).

During the first stage of data analysis, we examined and coded verbal transcripts of pre- and post- interviews and lesson plans for the mini-lessons. In this stage, we had an initial list of ideas about what was in the data and what was interesting about them (Braun & Clarke, 2006), then, started to code line by line (open coding) for five of the participants' interview transcriptions and artifacts (e.g. worksheet). In the same manner, the video data of prospective teachers' modeling implementation was coded. But, the coding in the video data included labeling word by word, action by action in the timeline while watching the videos using qualitative data analysis software, ATLAS.ti (Version 1.0.48). The qualitative data analysis software was used to code, organize, and categorize the codes systematically. In particular, in ATLAS.ti system, video-data can be coded easily and systematically. During the second stage of

data analysis, the researchers categorized each code and created concept maps using the categories. Then we made the decision to select central concepts related to the prospective teachers' knowledge of modeling and characteristics of instructional use of modeling practice. Then, the first author developed visual diagrams of categories and their relations. Braun and Clarke (2006) called this type of visual map a "thematic map" (p. 89) that has potential themes and sub-themes. Through the thematic maps, the researchers could link a concept to a concept, codes to codes. Later, we developed a revised thematic map with more details, category by category (axial coding). During the third stage of data analysis, themes were generated from the thematic concept maps, examining the relations, links, and associations between the codes and categories, and interpreting what the codes and categories meant theoretically.

The analysis process was repeated by re-reading transcriptions, as well as reading artifacts and analyzing video data until there were no longer emerging themes (Braun & Clarke, 2006). We frequently re-visited the literature and quotations from transcripts in the data to decide what the participants really meant and figure out if a code really fit the positioned category.

The first author coded all the transcripts and the other author coded a portion of the data, selecting a chunk of the data focused on significant parts in cases. Also, patterns and themes emerging from the data were negotiated and refined using triangulation (Janesick, 1994). For example, in the process of data analysis, we found that the initial emerging themes had many commonalities with the PCK framework (Park & Oliver, 2008). Therefore, we then independently re-coded the data, reflecting the PCK framework, and negotiated and reached a consensus about the codes.

Memos and diagrams

Memoing is important in grounded theory, because it is the researcher's conceptualizing process which draws integration of the analysis (Corbin & Strauss, 1990). In constant comparative method, memos are a tool for analysts' reflecting and taking their thinking to most logical conclusions (Glaser, 1965), so memos are "storehouses of ideas" generated through interactions with the data (Corbin & Strauss, 2008, p. 120). Corbin and Strauss (2008) described how writing memos and drawing diagrams force the analyst to think deeply about the data (p. 120). We also used memoing for developing ideas in the analysis process. In particular, we frequently used diagrams and maps which are useful tools to visualize concepts and linkages between concepts.

In this study, we used Park & Oliver (2008)'s PCK model as an analytic framework for understanding participants' PCK, knowledge of modeling; this framework is based on Magnusson, Krajcik and Borko (1999)'s PCK model in science education. In the PCK model (Park & Oliver, 2008), five components are identified: (a) Knowledge of Orientation towards science teaching (KOT), (b) Knowledge about science curriculum (KSC), (c) Knowledge of students' understanding of science (KSU), (d) Knowledge of assessment in science (KAS), and (e) Knowledge of instructional strategies (KIS). Among these components of PCK, the orientation for science teaching and self-efficacy are connected to teachers' beliefs about the purposes and goals for teaching science at different grade levels (Park & Oliver, 2008). The orientations to science teaching influence teacher practice by shaping other components of PCK (Friedrichsen & Dana, 2005; Grossman, 1990). The reason why we selected this model is that Park & Oliver (2008)'s model emphasized the integration of PCK components. Park and Oliver (2008) did not test this model with prospective science teachers and are unsure of how

representative it is for characterizing the knowledge of teachers who have minimal experience with teaching. One of those authors feels as though the analog to PCK that exists among pre-service teachers should be labeled as Proto-PCK since it is a primitive form of PCK and will possibly (but unreliably) be remembered and employed by the prospective teachers when they are fully involved in the profession of science teaching as career science teachers (Oliver, pers. com., 2017). In this analysis, linkages were made to the components of the PCK model above by coding statements within plans as well as those made during interviews that followed mini-teaching experiences.

Nelson & Davis (2012) in their study of prospective elementary teachers' evaluation of elementary students' scientific models, identified pedagogical content knowledge for scientific modeling (PCK-SM: Pedagogical Content Knowledge - Scientific Modeling). These authors' PCK-SM is also based on Magnusson et al. (1999)'s PCK model. In their identification, they suggested the elements of five PCK-SM components. In this study, we drew upon the components of PCK for modeling and elements of each component from Nelson & Davis (2012)'s PCK-SM, mirroring Park & Oliver (2008)'s Proto-PCK for another level of analysis of secondary prospective teachers' PCK.

From the inductive analysis of cases, we found the prospective teachers developed knowledge of modeling, while designing and implementing modeling instruction, that could be coded into categories that duplicated the PCK components. Then, we re-visited the data and compared categories and codes with Park & Oliver (2008)'s categorization of PCK (We call 'Proto-PCKm': Proto-PCK for modeling). We refined codes and categorized codes based on the Proto-PCKm, looking at how each code reflected the element in PCK components. In addition, we analyzed the connections among PCKm components by interpreting what PCKm components

each quote represents. In other words, if a quote of a participant described KISm, but at the same time, it contained KSUm, the quote had two codes, KISm and KSUm.

Table 3.2 shows Components of PCK for modeling and element adapted from Park & Oliver (2008)'s model and Nelson & Davis (2012).

Table 3.2 Components of PCK for scientific modeling and element. (Adapted from Park & Oliver (2008) and Nelson & Davis (2012, p. 1935).

Proto-PCK for modeling (Proto-PCKm)	Element of PCKm (Adapted from Nelson & Davis, 2012, p. 1935)
Orientations toward science teaching using modeling (KOTm)	Orientations in the use of modeling pedagogies. e.g.) willingness to teach science using models/modeling
Knowledge about modeling in science curriculum (KSCm)	When modeling is appropriate for the curriculum; how to incorporate modeling into curricula; which topics are appropriate to modeling; which modeling practices can be used, etc.
Knowledge about instructional strategies in science using modeling (KISm)	When and how to use modeling instructionally; when and how to support students in learning about modeling.
Knowledge of assessment in science using modeling (KASm)	How to assess students' content and scientific practice using modeling; when to use modeling to assess students' understanding of content and scientific practices.
Knowledge of students' understanding of scientific modeling (KSUm)	How students understand science content represented in models; students' understanding of scientific modeling practices, epistemology, and nature of models; how to interpret and critique student-generated models.

Findings

In the section that follows, we contrast three representative cases to discuss the characteristics of knowledge that prospective secondary teachers developed during an instructional session focused on modeling implementation. Then, we will discuss what components of PCKm were developed with respect to each case.

PART I

Characteristics of Development of Instructional Knowledge of Modeling

In the following section, we describe three cases among the five participants, highlighting different important aspects of their modeling implementation to answer our research question 1. Each of these cases is based on the mini-lesson teaching conducted by the groups of prospective secondary science teachers with elementary prospective teachers serving as students. The five research participants were assigned to work in separate groups.

Jodice – Awareness of Game as an Effective Modeling Tool

In Jodice's case, we highlight his realization and development of the instructional knowledge that a game can be an effective modeling tool. Jodice's group designed a modeling activity that consisted of an energy game through which learners would explore energy relationships resulting from collisions between marbles. Jodice's group used the modeling game to introduce potential and kinetic energy and help prospective elementary teachers explore energy conversion between potential and kinetic energy as well as energy transfer that occurs as a result of a collision. The group prepared several bulls-eye marked and circled with tape on the carpet in the hallway (see *Figure 3.2*). Each group was provided with a big circle with one bull's eye at the center surrounded by concentric rings, and each ring had a different point value. Five

small marbles were placed together in the center of the bull's eye. In this activity, the goal was to drop a marble to hit the five small marbles placed in the center of the bull's eye and get as many of the marbles to go outside of a circle as possible using the falling marbles' momentum to propel them. The elementary teachers earned more points if they were able to get the marbles to go outside of the circle. *Figure 3.2* shows the design of the energy modeling activity.

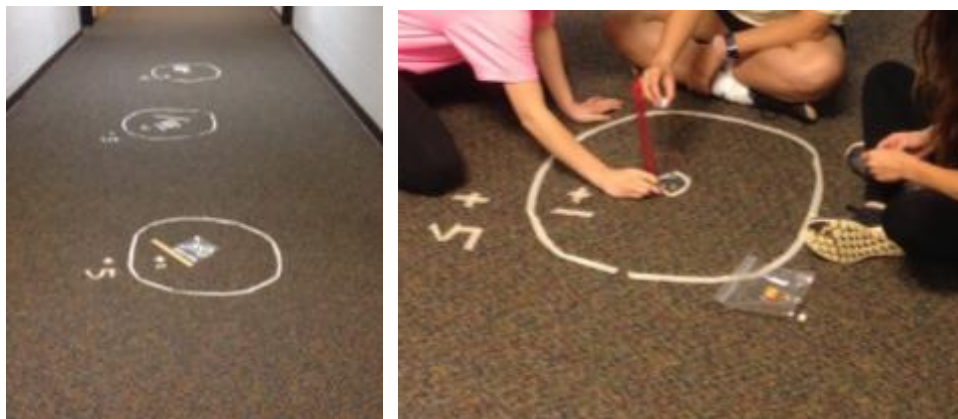


Figure 3.2 Energy modeling activity with marbles

Through the game, the prospective elementary teachers were able to model energy transfer/conversion conceptually in the process while exploring the energy game with marbles. During the energy game, the learners predicted whether dropping a marble from different elevations would make the stationary marbles on the bullseye go further. The correctness of their predictions was linked to earning more points. From the game, elementary prospective teachers could figure out how height relates to potential energy, and how potential energy can be converted to kinetic energy during free-fall and then transferred through a collision into the stationary marbles' movement. Immediately after the game, the prospective elementary teachers discussed the activity with each other. When the prospective elementary teachers were asked "Who got the highest score? What did you use to get the highest score?", the student who obtained the most points said, "I used the bigger marble at three inches high." Many of the

prospective elementary teachers could explain the role of “energy transfer” when they were asked “why is that? Can anybody tell me what happens there?” Then also explained how “energy is something to do work” when asked “what is the energy?” From the video data analysis (Video 1-1, Jodice’s group, 11/19/15) of this discussion, the researchers and Jodice noticed how quickly the prospective elementary teachers figured out the concepts of potential and kinetic energy and energy transfer in relation to mass, height, and energy. When the prospective elementary teachers were asked “why is that? Can anybody tell me what happens there?” many of them also could answer “energy transfer”. Then, when they were asked, “what type of energy does this marble have before it is dropped?” (indicating the arrow while falling the marble in diagram on the screen) the entire class responded, “potential energy”. Similarly, when asked “what sort of energy does this marble have when shooting the marbles?”, the class responded with “kinetic energy”. Finally, Simon explained, “as the potential energy decreases the kinetic energy increases”, and most prospective elementary teachers nodded in agreement. When Melissa, one of the secondary prospective teachers, asked the elementary prospective teachers to describe an equation for potential energy at the beginning of the discussion, every prospective elementary teacher responded “No~” But, step by step, Melissa reminded them of the game and asked, “what factors in? you guys already know the answer, what major marbles shoot (the marbles)?”. The prospective elementary teachers were encouraged to think about the factors based on their experience with the marbles and they could discuss factors needed to construct ideas of potential energy such as “gravity”, noting that the marbles have some “mass”, and “height”. Melissa responded “So you all just came out with the equation for potential energy.” The moment the prospective elementary teachers recognized characteristics of potential energy was a teachable

‘Aha-moment’ for all. Jodice recognized this moment could not be generated otherwise without the energy game modeling experience (Video 1-1, Jodice’s group, 11/19/15).

A game itself does not always serve as a model, but in this particular case, the energy game worked as a modeling activity. In particular, this example illustrated a conceptual model. Jodice found that the prospective elementary teachers were very engaged in the energy game. He discussed the relationship between potential and kinetic energy right after the game. Jodice and his other group members noticed that the prospective elementary teachers immediately understood the concept of energy transfer. Jodice came to value the experience of modeling energy transfer through the game.

They were having a good time. They were learning. They were trying to understand. “So, maybe it’s better if we drop from a higher height.” “Oh, maybe I’ll try the bigger marble”... and let kids just explore and that by the time we went inside and started discussing the real factors associated with what they were looking at, they understood it extremely quickly, which I love. (Jodice, interview, 12/14/15).

Jodice viewed the model aspect of the activity as a conceptual model. He considered the game itself as a type of modeling that could be used to show the factors that influence energy transfer/conversion phenomenon between potential and kinetic energy. Jodice felt that the game was an effective modeling strategy for teaching the transfer of potential and kinetic energy, noting:

These models were mostly mental model like we didn't create anything but by forcing them to play this game, they were having to figure out what the relationship was between height and the way the impacts lay and where things went. And they saw it as a game but really what they didn't realize they were developing models for collisions and physics and

when we got to the classes started explaining how all of this worked and how kinetic energy and potential energy worked, they realized that just in trying to succeed at the game they developed conceptual understandings that they didn't realize they figured out.” (Jodice, interview, 12/14/15).

After the modeling implementation, Jodice acknowledged his recognition of the effectiveness of games, as a form of modeling, for student learning. In addition, he was impressed with how the modeling activity could foster enjoyable moments as well as develop conceptual understandings.

Jodice also noted his growing awareness of attending to how students respond to an activity, important instructional knowledge involved in modeling.

I love the idea that modeling activities don't have to be very large and that are really complicated and take a lot of instruction time. Sometimes they can be things that you set up in five minutes and let kids just explore and that by the time we went inside and started discussing the real factors associated with what they were looking at, they understood it extremely quickly which I love.” (Jodice, interview, 12/14/15).

In addition, Jodice noticed how different forms of modeling operate in a modeling activity. After the elementary teachers had collected their data in the energy game with marbles, Jodice’s group utilized a diagram, a formula, and a graph as other forms of models to clarify the phenomenon using different explanation formats. In essence, the group used multimodal models to explain the same phenomenon. As part of the groups’ lesson implementation, they used an equation for potential and kinetic energy ($KE = .5 \times \text{Mass} \times \text{Velocity}^2$ and $PE = \text{Mass} \times \text{Height} \times \text{Gravity}$), a diagram and a graph to illustrate the change in kinetic and potential energy of a

falling marble and to explain energy transfer and the total mechanical energy to the prospective elementary teachers. Jodice explained,

We showed them a diagram of the model as well but that was only to clarify so they could look at a different angle [than] what they were working on...we didn't let them draw the model, we displayed [for] them the model of what they were doing. (Jodice, interview, 12/14/15).

Figure 3.3 shows the diagrams that Jodice' group used to explain energy transfer on the screen using PowerPoint.

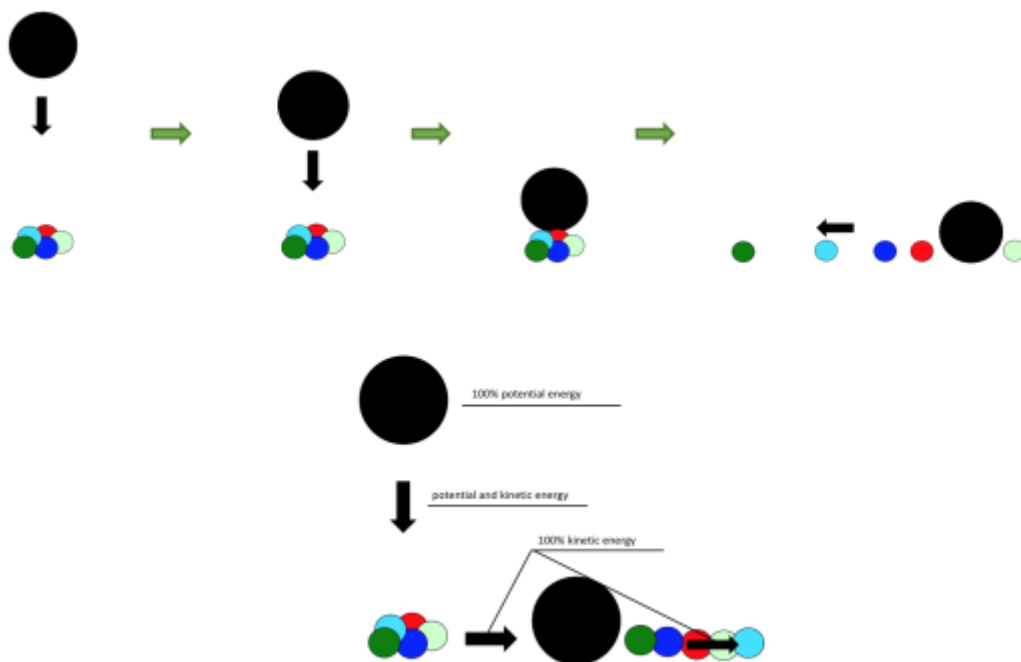


Figure 3.3 Diagrams to show energy transfer when a big marble falls and hits five small marbles in the energy modeling game.

The researchers found the implementation of the modeling instruction enhanced Jodice's knowledge of instructional strategies using modeling. Jodice realized that using games as an effective and enjoyable modeling tool could be an effective instructional strategy. He also realized that using multimodal models (e.g. diagram, graph, equation, etc.) to show a

phenomenon from different perspectives can be meaningful to learners. Jodice felt that he was able to generate modeling PCK that otherwise might not have been possible. The specific nature of this modeling PCK will be discussed in Part II.

Denise – An Embodied Learning Approach to Modeling

Denise developed instructional knowledge related to how using students' body movement can be an effective modeling strategy. Denise had research experiences in chemistry laboratories and was pursuing both science education certification and a master's degree in chemistry at the same time. At the beginning of semester, Denise said she was aware that modeling practice is emphasized in the NGSS as it was introduced earlier in a class she took over the summer. However, she emphasized that while they learned about modeling they had little practice with it in summer class. In her first interview, she shared that she had never thought about modeling too much as a practice.

I've never really thought about it too much, because it was never described as this is a practice. It's more of like you'll see it, they show you this is a model of an atom, and you'll see the model. They don't think of that specifically as a practice.” (Denise, Interview, 10/05/15).

She had an idea of the importance of modeling as practice, in particular, as student-centered practice (e.i. students' own modeling practice) in science classrooms rather than the use of models by teachers. Denise also wondered if and how models could be completely connected with content in a classroom instead of a stand-alone practice,

Sometimes I wonder if the model is just we can learn a model or how to use some modeling or if it's actually information that would be relevant to teach to a certain class.

So how can that be completely connected with the content that you need and to learn?
(Denise, Interview, 10/05/15).

She explained how this question was a challenge to her understanding of modeling, especially, in her content area, chemistry. Denise explained,

Modeling in general is always more easy to do with biology ideas. I see more models with biology, like the biology textbook has lot of diagrams. There's a lot of simulations of biological events and even at a cellular level and you know chemistry is more like you have models, atom models, molecules and maybe some models of book materials, but I don't think there is really that much involvement in chemistry most of the time. I think maybe engineering models would come in more with chemistry. That's something that I would like to know how to connect, because I think students think chemistry is very abstract and if you can make it visual and interactive with modeling, I think that would help. So I would like to know my content area how that could be as a modeling.” (Denise, Interview, 10/05/15).

Denise really wanted to connect modeling with her content area because she thought that modeling was a way to make chemistry content more relevant to students. But based on her statement, she was unclear about how to think about models in chemistry other than those traditional forms (i.e. atoms and molecules) that are part of the typical textbook presentation. She already had observed how the characteristics of models could be beneficial to student learning by making abstract concepts visual and interactive. In addition, when compared with biology, she felt that chemistry needed to be taught in ways that were more relevant to students and she felt that modeling could be helpful to students in this respect. Denise had an idea of the importance of teaching about models as well as modeling as a scientific practice. Because she viewed

content as a connection between students and science, she felt that modeling could function to foster meaningful ways of learning for students.

Denise's group prepared the modeling mini-lesson around the topic of phase changes of water (Got Any Change?). They created a gesture game as a modeling activity so that students could learn how heat changes phases of water with body movement. Although this group labeled their activity as a game, it was more of a form of play since there was no way for someone to "win". The group mapped the phenomenon of how heat changes phases of water (referent) onto the game (model) as a modeling activity. First, they had the elementary prospective teachers make headbands with a water droplet shape on the front of their heads to represent an individual teeny-tiny water droplet. They cordoned off three sections in the hallway to represent solids, liquids and gases. The solid area was small in size so that the "modelcules" (students) could not move much. The liquid area was larger, and the gas area the biggest, so that the gas molecules could move freely. At the beginning, all elementary prospective teachers began as ice packed into the solid section. They tried to move as much as they could, jiggling in place due to space constraints. They mentioned this modeled vibration of particles in solids. One of the prospective secondary teachers used a red balloon to tag (add heat to) the solid water, causing the solid to melt. The instructor started to tag students individually. The elementary prospective teachers that were tagged moved into the liquid water area where they were required to link hands. Denise's group described this as modeling the movement of particles in the liquid state. If the elementary prospective teachers in the liquid state were tagged with the red balloon again individually, they moved to the gas section. In this case, tagging with the red balloon meant the gain of heat and then subsequent evaporation. In the gas phase area the prospective elementary teachers could move freely. Denise's group explained how this was modeling the random, fast movement of gas

particles. Next the prospective secondary teacher began to tag students with a blue balloon, to simulate cooling of the molecules. The students who were tagged with a blue balloon moved back into the liquid area and rejoined hands in order to model condensation. The same process was done for freezing by cooling them down further. Finally, all students returned to the solid state, and discussed what they had learned in the modeling activity. Denise explained,

After that, we can tag them with the red balloon again and they get more heat and can evaporate and they have a lot of space in the area where the gas container and they can run around the whole container. Then we can go through the same process with the blue balloon and cool them back down so that they can dance and they freeze again. That's the game." (Denise, Interview, 12/16/15).

Denise intended for heat to be added first, followed by cooling later so that the elementary teachers would use the strategy to calm down students and have them focus and resume a discussion on what they learned about phase changes through the modeling activity. In the video recording (Video 2-2, Denise's group, 11/19/15), Denise explained that she intended to handle behavior by organizing the activity using the sequence of heating and freezing.

The reason that we had them start out at solid, and then get back to solid at the end is because hopefully kind of wound out a little bit, but the time they get back to, not being able to move this much, so kind of thought of that as a little bit, of like controlling some behavior helping them not to go completely crazy." (Video 2-2, Denise's group, 11/19/15).

This knowledge of an instructional strategy for handling learners' behaviors in relation to the appropriate developmental age is an important aspect of teacher knowledge. In the PCK model, knowledge of instructional strategies includes knowledge of topic specific representations

and activities (Magnusson et al. 1999), and how students can be influenced by the representations and activities. Also, this knowledge is integrated with knowledge of students' understanding which is associated with developmental levels and learning styles of students, particularly in relation to specific content. Denise thought about how students would be influenced by the modeling activity; then she organized the sequence of the activity in consideration with handling learners' behaviors.

Denise's group members demonstrated competency in the use of models, mapping phases of water molecules' movements and heat transfer onto the structure of the game using analogical thinking, an essential skill in modeling. Denise's group activity was a good example of modeling through the use of gestures and body movements. Denise recognized the importance and effectiveness of the gesture game and body movement for student understanding with modeling. Scherr et al. (2013) addressed how embodied cognition with collective body movement can enhance the construction of a model, conceptual engagement, and the generative basis for instruction by "constructing meanings by means of body placement, orientation, gesture, and other bodily actions." (p. 3). From the video data of the modeling activity and subsequent discussion, Denise's group and the prospective elementary teachers talked about labeling gas, liquid, and solid in the three sections of area in the hallway, so that children would be able to visually observe the labels. One of the prospective elementary teachers mentioned how this could help students conceptualize the phases of water. Some prospective elementary teachers suggested that children could yell 'gas, liquid, solid' when they entered the area representing each stage. During the modeling activity, the prospective elementary teachers as well as Denise's group generated effective instructional ideas to use modeling for teaching elementary students.

Through the activity, Denise wanted students to understand how the molecules moved in each different phase. For instance, she wanted to point out that water molecules when they're frozen are still moving, something she felt was not easily recognized by students due to invisibility of the molecules. Denise explained,

We had regions in the room that were set up with tape to confine students to a certain container size and so for the area where there were ice, it was a small area and the students had to be very close together and they started out there and they are told that they need to move around as much as they can and since they're in an enclosed space, they're really just wiggling in the space so that's to help them understand that water molecules when they're frozen are still moving. But we didn't use the word molecules, we used the word droplets. We would tag them with a red balloon and they then are getting heated up so they can move from the ice and melt and become liquid water and once all of the kids are in that area, there's more room and they can move around but they still can't move very fast or they'll crash into each other.” (Denise, Interview, 12/16/15).

Denise's group utilized the analogy “movement” of molecules in each phase of water by letting students express body movement, and guided them to recognize the relationship between invisible movement of molecules and visible phases of water.

In addition, Denise became more aware of the appropriate use of scientific terminology in modeling from the elementary prospective teachers' feedback about the modeling activity. This finding is consistent with Nelson & Davis (2011)'s study on elementary prospective teachers' model evaluation.

So, I think that was a little bit difficult but – and a lot of the suggestions for feedback that we got, were saying we should use more of the terminology with the students during the

game. I think the game could be modified to use the terms more and I mean it would be probably used in combination with drawings or other labs and things that would help the kids understand it more than just the game. That lesson would not be the only thing that the kids would see for the phases matter. (Denise, Interview, 12/16/15).

Knowledge about the use of terminology in the modeling activity was particularly evident in Denise's case. Initially Denise thought the term 'molecule' would be difficult for elementary students, so that she didn't want to introduce the term in her group's implementation of the activity as a model of instruction for prospective elementary teachers. However, after the mini-lesson and feedback from prospective elementary teachers, Denise's consideration of the use of appropriate scientific terminology in science classrooms was deepened alongside her instructional knowledge. Denise's concern about terminology was directly connected to her belief that the modeling activity in the form of a game was ultimately intended to help children understand scientific content/concepts. With this in mind, Denise also became more aware of the need of the use of diverse forms of modeling, for example, in combination with drawings or labs, so that students could develop deeper understanding of the phases of matter. In Denise's case, her group also wanted to convey scientific concepts to students through modeling. However, as in the activity of Jodice's group, the prospective elementary teachers were provided with the model instead of guided through scaffolding to generate their own models. Denise mentioned the importance of students own generative modeling practice in science classrooms. This might be because of time limitation in the mini-lesson, however, it is obvious that developing students' own models as expressed forms was not priorities in her group's activity in a given time.

Chris – Modeling with Lab Activity for New Knowledge

Chris's group incorporated a laboratory activity in designing their modeling mini-lesson. Chris had prior research laboratory experience and understood well what scientists do in developing new knowledge. The modeling activity developed by his group centered around the topic of blood pressure. His group prepared glue, straws, water, and containers. The glue represented the blood clots found in blood vessels, and the straws were used to represent the blood vessels. In this case, the model was a system of blood vessels with blood clots. In the modeling activity, the prospective elementary teachers placed the "blood clot" (glue) into the straw and then had water enter the straw like blood. Chris and his group thought this analogy would help the prospective elementary teachers understand how a blood clot works and how it relates to blood pressure. Chris took on the role of main instructor for the mini-lesson and asked the prospective elementary teachers: "when we put glue into the straw, what happened to the blood?" He used the answers from the elementary teachers as an anchor to explain how cholesterol functions as well as how cholesterol works negatively in our body in relation to blood pressure. Chris thought that with analogical reasoning and a concrete modeling activity, the prospective elementary teachers could develop an understanding of how blood clots work positively and negatively in our blood vessels. For example, in the worksheet of the mini-lesson, Chris listed three different levels (elementary, middle, and secondary levels) of questions that could be used to develop conceptual models of how cholesterol relates to blood pressure. Only his group tried to prepare three different levels of questions, adjusting students' levels of understanding. He asked in the worksheet, "For this lab, what does the glue represent in our bodies? Since you know what it is, what are some ways you could reduce the amount of "glue" in you?" in elementary level questions. For middle school level, "Is all cholesterol "bad" for

you? What does cholesterol do for you? How can you make sure your cholesterol levels are healthy?” and for the high school level, he mentioned the difference between HDL and LDL cholesterol in the same purpose. In addition, later in the interview, he described the levels this way,

The more we thought about it, the more we could apply it on a plethora of different levels. You can make it as super simple as you want or very, very complicated and that's what I liked about the activity a lot. (Chris, interview, 12/16/15).

Chris realized that he could adjust the modeling activity and scientific terms for different levels of student understanding from this modeling implementation experience.

It seemed that his explanations gained the prospective elementary teachers' interests and attention, especially because the topic was closely related to their bodies, diseases and everyday lives. Not only that, the prospective elementary teachers seemed to be enjoying learning new knowledge from the modeling activity. Based on the video data analysis, it was clear that they asked many questions about the blood clots and health. For example, Chris explained that blood clots help to stop bleeding, such as when we get a paper cut. He elaborated on this to explain that sometimes blood clots break free from blood vessels in our body and when this happens they can be dangerous and lead to serious medical conditions. Prospective elementary teachers asked questions such as “if we take the medicine, some of the medicine fence the clot...what is happening now?” or “what's the really bad food for?” The prospective elementary teachers were actively engaged in the discussion on the topic through the modeling activity.

During the modeling activity, Chris and his group member, David, emphasized how modeling provides a great visual representation of the blood clots and the blood pressure, how something affects the human body and how the body responds to it, as well as how the activity

could be adapted for an elementary science classroom. From this implementation, Chris realized that modeling is beneficial for students as a means to learn new knowledge. Later in his interview, Chris stated,

I think the model showed...something that they hadn't known about blood flow and clots...when we put the 'blood clot' in there, into the straw, which was just a clump of glue, and on almost every single table, the clot was pushed out by the water, and then, 'Oh, well, it's gone.' I was like, 'That's a good point. Blood clots move. They don't just break apart all the time; they move throughout the body.' And, a lot of them had never really thought about that; so that was pretty cool. (Chris, interview, 12/16/15).

Through the modeling activity, the prospective elementary teachers observed and discovered how the moving glue represented another important characteristic of blood clots in our body. Manz (2012) recognized that modeling has "a highly material face" (p. 1072). She shared an example from Nersessian and Patton (2009)'s study of how biomedical engineers try to understand how blood vessels work with the "flow loop", emphasizing how they iteratively redesign and test their models to know how blood vessels work. This example seems similar to Chris' use of a material (physical or concrete) model to understand a "blood clot". Through the modeling activity, the prospective elementary teachers predicted and realized that blood clots have the potential to move throughout the body. Chris noticed that, as the prospective elementary teachers observed how the water pushed glue away from the wall of the blood vessel (straw) during the modeling activity and later Chris pointed out that blood clots are not stationary explicitly and when the prospective elementary teachers discussed the phenomenon, it was evident they understood how blood clots could be moving in our body. The concrete model

clearly showed the possibility of blood clots' moving through the blood vessels and facilitated new understandings of blood clots based on data collected as part of the lab activity.

From the modeling implementation experience, Chris realized the power of analogical thinking through modeling in understanding a new phenomenon. Chris felt that this modeling strategy was effective and could be adjusted for many different developmental ages. After the lesson, Chris realized that a more explicit intrinsic representation of blood was needed, perhaps by using red food coloring.

One of the biggest complaints was that we're doing this activity pretending that the water is blood and then like we should have used red food coloring. I guess our challenge there was it didn't look realistic enough but this is one of the problems with models. You can always improve a model but the point was ... you know what the point was. (Chris, interview, 12/16/15).

However, he also mentioned that what was most important was to help the prospective elementary teachers understand the purpose of the modeling experience. He asserted the need for more openness in designing modeling tasks, and the need to emphasize the incompleteness of modeling, meaning that models can be revised always.

The most difficult thing to really come to realize is that your model will never be complete. You will make the most perfect model in the world and since it is not the real thing by definition, it won't work the same way...You can always think of ways to improve them but that's kind of the point, like if you try to make a model of a boat and it keeps on sinking, it keeps on sinking, you finally make one that floats, okay, well how will it work in the ocean. It's obviously going to sink again because if you're making a boat in a bucket in a classroom. (Chris, interview, 12/16/15).

He stressed the importance of uncertainty in the modeling experience. In addition, Chris mentioned that if this modeling activity was more structured, teachers would not be able to see students' misconceptions and the activity would not be open to the model's revision. "... in terms of teaching, if you were to guide students making the model. They would never put their misconceptions. They would never put their faults in the model." (Chris, interview, 12/16/15).

PART II

Crosscase Analysis of Prospective Teachers' PCKm

In this section, we discuss our analysis of the prospective teachers' Pedagogical Content Knowledge of Modeling (PCKm). Based on the lens of Park & Oliver (2008) and Nelson & Davis (2012)'s categorization, we identified the PCKm that the prospective teachers developed from the three cases.

Jodice – KISm & KSUm

Table 3 shows Jodice's development of PCKm. Jodice mostly demonstrated development in the knowledge of instructional strategy for modeling (KISm). Knowledge of instructional strategy for modeling (KISm) is about, 1) when and how to use modeling instructionally, and 2) when and how to support student learning about modeling (Nelson & Davis, 2012). He also developed the knowledge of students' understanding of modeling (KSUm) the second most. *Figure 4* illustrates the development of PCKm for Jodice, comparing how much each component developed through the modeling mini-lesson implementation.

Table 3.3 Jodice's Development of PCKm

Proto-PCK	Examples from Jodice's reflections on teaching in follow-up interview
KOTm	<ul style="list-style-type: none"> a. Aha-moment quote speaks to Jodice's growing recognition of his orientation to teaching science. b. Jodice also noted his growing awareness of attending to how students respond to an activity
KSCm	<ul style="list-style-type: none"> a. Used the modeling game to help elementary PSTs explore kinetic and potential energy. b. Used game to help elementary PSTs learn about energy transfer c. Jodice quote, "discussed the real factors associated with what they were looking at" (the factors that influence energy transfer/conversion phenomenon).
KSum	<ul style="list-style-type: none"> a. Melissa responded "So you all just came out with the equation for potential energy." The moment the prospective elementary teachers recognized characteristics of potential energy was a teachable 'Aha-moment' for all. Jodice recognized this moment could not be generated otherwise without the energy game modeling experience. b. Jodice quote "They were trying to understand. "So, maybe it's better if we drop from a higher height." "Oh, maybe I'll try the bigger marble" c. Jodice quote, "they were having to figure out what the relationship was between height and the way the impacts lay and where things went" d. Jodice quote, "they didn't realize they were developing models for collisions and physics" e. Jodice quote, "These models were mostly mental models" f. Jodice quote, "they realized that just in trying to succeed at the game they developed conceptual understandings that they didn't realize they figured out."
KASm	<ul style="list-style-type: none"> a. Jodice quote, "discussed the real factors associated with what they were looking at" (the factors that influence energy transfer/conversion phenomenon).
KISm	<ul style="list-style-type: none"> a. Created modeling activity as a game for elementary PSTs. b. "Aha-moment" quote above also speaks to Jodice's recognition of the value of this instructional strategy c. Jodice acknowledged his recognition of the effectiveness of games, as a form of modeling, for student learning d. "growing awareness" from KOT. e. Jodice quote: "I love the idea that modeling activities don't have to be very large..." f. Jodice quote: "We showed them a diagram of the model as well but that was only to clarify so they could look at a different angle what they were working on..." g. Jodice realized that using games as an effective and enjoyable modeling tool

could be an effective instructional strategy.

- h. Jodice quote, “they didn't realize they were developing models for collisions and physics”
- i. He also realized that using multimodal models (e.g. diagram, graph, equation, etc.) to show a phenomenon from different perspectives can be meaningful to learners.

(a) Orientations toward science teaching using modeling (KOTm), (b) Knowledge about modeling in science curriculum (KSCm), (c) Knowledge of students’ understanding of scientific modeling (KSUm), (d) Knowledge of assessment in science using modeling (KASm) and (e) Knowledge about instructional strategies in science using modeling (KISm)

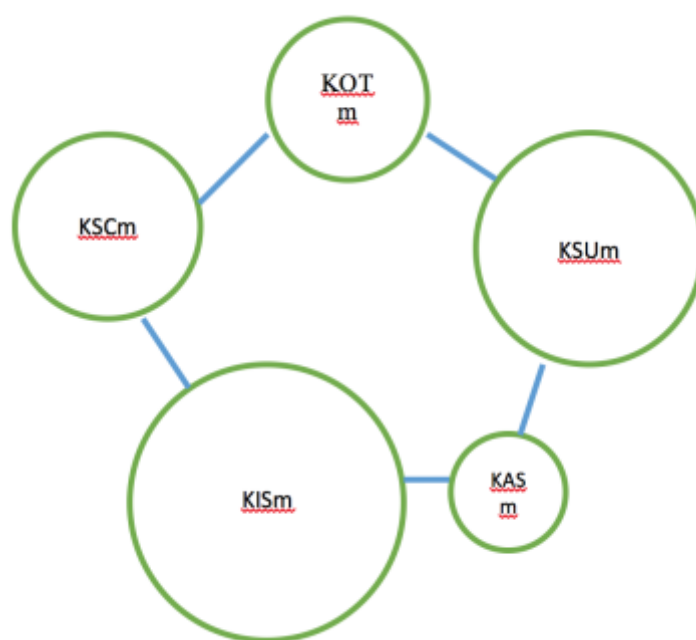


Figure 3.4 Jodice's development of PCKm

In addition, we analyzed the interconnectedness of PCKm for Jodice. We found Jodice had two different combined insights in a quote which can be considered as interconnectedness among PCKm components. For example, in one of Jodice’s comments, he provided acknowledgement of student learning through modeling, “they didn't realize they were developing models for collisions and physics” (Jodice, interview, 12/14/15), Jodice realized how the game was an effective modeling tool to learn collisions and physics (KISm), however, he

also noticed students didn't realize they were developing models at that time. This insight has characteristics of knowledge of how students respond and understand modeling (KSUm) in the activity. *Table 3.4* illustrates Jodice's quotes and their interconnectedness among PCKm components. We included only quotes which have combinations of PCKm components in *Table 3.4*. In Jodice's case, the strongest connections were between KISm and KSUm; KISm and KOTm showed connections that were less strong. However, KISm was central to Jodice's description of the relationships between PCKm components. The finding that Jodice demonstrated an awareness of the strong interconnections between KISm and KSUm among PCKm components is consistent with Park & Chen (2012)'s analysis of PCK Maps. Park & Chen (2012)'s research emphasized practicing high school biology teachers development of PCK (not particularly in modeling), but our findings illustrate how prospective teachers also recognize the interconnectedness of KIS and KSU among PCK components.

Table 3.4 Jodice's interconnections of PCKm components

Statement	KOTm	KSCm	KISm	KASm	KSUm
Aha-moment quote also speaks to Jodice's growing recognition of his orientation to teaching science: Melissa responded "So you all just came out with the equation for potential energy." The moment the prospective elementary teachers recognized characteristics of potential energy was a teachable 'Aha-moment' for all. Jodice recognized this moment could not be generated otherwise without the energy game modeling experience.	√		√		√
Jodice also noted his growing awareness of attending to how students respond to an activity	√		√		
Jodice acknowledged his recognition of the effectiveness of games, as a form of modeling, for student learning			√		√
Jodice quote, "they didn't realize they were developing models for collisions and physics"			√		√
Jodice quote, "they realized that just in trying to			√		√

succeed at the game they developed conceptual understandings that they didn't realize they figured out.”					
“I love the idea that modeling activities don't have to be very large...”	√		√		
Jodice realized that using games as an effective and enjoyable modeling tool could be an effective instructional strategy.			√		√
Jodice quote: “We showed them a diagram of the model as well but that was only to clarify so they could look at a different angle what they were working on...”			√		√

Denise's PCKm - Development of KSCm

Table 3.5 illustrates Denise's development of PCKm. Denise showed a fairly balanced development among the PCKm components. For example, she clearly developed KSCm, KISm, and KSUm. However, Denise, among the primary participants of this study, demonstrated the greatest development in the knowledge about modeling in science curriculum (KSCm). The knowledge about modeling in science curriculum (KSCm) is evident when the teacher has insight to when modeling is appropriate for the curriculum and how to incorporate modeling into curricula. For example, which topics are appropriate to modeling and which modeling practices can be used for the topics (Nelson & Davis, 2012). However, from among the three cases, only Denise did not demonstrate an understanding of the development of knowledge of assessment using modeling (KASm).

Table 3.5. Denise's Development of PCKm

Proto-PCK	Examples from Denise's reflections on teaching in follow-up interview
KOTm	a. the importance of students own generative modeling practice

KSCm	<ul style="list-style-type: none"> a. “how to use some modeling or if it's actually information that would be relevant to teach to a certain class” b. we didn't use the word molecules, we used the word droplets. c. We would tag them with a red balloon and they then are getting heated up so they can move from the ice and melt and become liquid water d. we should use more of the terminology with the students during the game. e. That lesson would not be the only thing that the kids would see for the phases matter.
KSUm	<ul style="list-style-type: none"> a. One of the prospective elementary teachers mentioned how this could help students conceptualize the phases of water. Some prospective elementary teachers suggested that children could yell ‘gas, liquid, solid’ when they entered the area representing each stage. b. how to organize the order of modeling activity: “the time they get back to, not being able to move this much, so kind of thought of that as a little bit, of like controlling some behavior helping them not to go completely crazy.” c. I mean it would be probably used in combination with drawings or other labs and things that would help the kids understand it more than just the game
KASm	
KISm	<ul style="list-style-type: none"> a. how to organize the order of modeling activity: “the time they get back to, not being able to move this much, so kind of thought of that as a little bit, of like controlling some behavior helping them not to go completely crazy.” → Linkage of the knowledge of students’ understanding associated with developmental levels b. I mean it would be probably used in combination with drawings or other labs and things that would help the kids understand it more than just the game c. the use of diverse forms of modeling, for example, in combination with drawings or labs

(a) Orientations toward science teaching using modeling (KOTm), (b) Knowledge about modeling in science curriculum (KSCm), (c) Knowledge of students’ understanding of scientific modeling (KSUm), (d) Knowledge of assessment in science using modeling (KASm) and (e) Knowledge about instructional strategies in science using modeling (KISm)

In the same manner, we illustrated the relative development of PCKm components for Denise, shown in *Figure 3.5*.

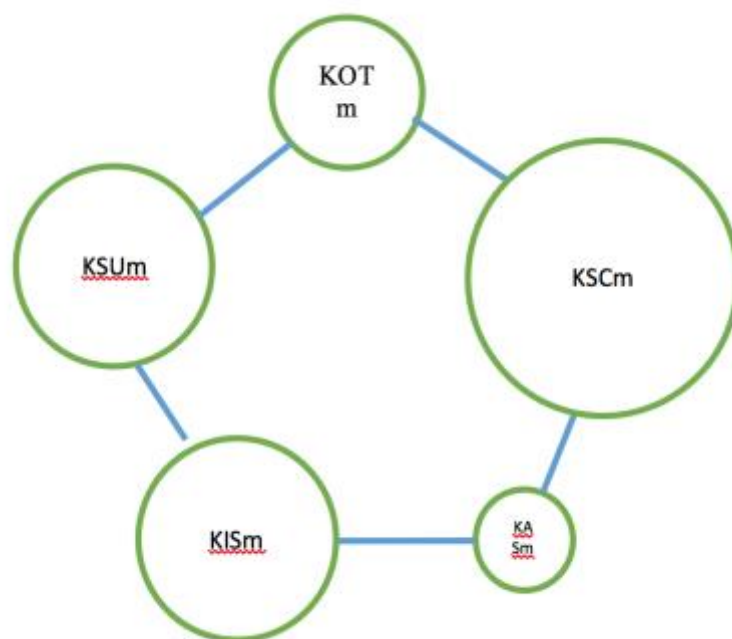


Figure 3.5 Denise's development of PCKm

Denise demonstrated the greatest number of interconnections between KISm and KSUm, and between KSCm and KISm. One of her quotes illustrated connections among all KISm, KSUm, and KSCm. The analysis of the interconnectedness of PCKm for Denise is partially consistent with Park & Chen (2012)'s finding. It is consistent with Park & Chen (2012)'s research in that KISm is central among PCKm. However, the connections between KISm and KSUm, and between KISm and KSCm were equally presented. *Table 3.6* illustrated Denise's quotes and interconnections among PCKm components.

Table 3.6 Denise' interconnections of PCK components

Statement	KOTm	KSCm	KISm	KASm	KSUm
How to organize the order of modeling activity: "the time they get back to, not being able to move this much, so kind of thought of that as a little bit, of like controlling some behavior helping them not to go completely crazy."			√		√
I mean it would be probably used in combination with drawings or other labs and things that would help the kids understand it more than just the game			√		√

we didn't use the word molecules, we used the word droplets.		√			√
We would tag them with a red balloon and they then are getting heated up so they can move from the ice and melt and become liquid water.		√	√		√
we should use more of the terminology with the students during the game.		√	√		

Chris - KSCm and KISm

Table 3.7 illustrates Chris' development of PCKm. Chris demonstrated primary development in KISm among his PCKm components. Also, Chris showed the greatest development of PCKm components as well as the most interconnections of PCKm components among three participants. In addition, Chris demonstrated an understanding of the strong connectedness between KSCm and KISm, similar to Denise's case.

Table 3.7 Chris' Development of PCKm

Proto-PCK	Examples from Chris' reflections on teaching in follow-up interview
KOTm	a. Realized that modeling is beneficial of students as a means to learn new knowledge.
KSCm	a. This analogy would help the prospective elementary teachers understand how a blood clot works and how it relates to blood pressure. b. He used the answers from the elementary teachers as an anchor to explain how cholesterol functions c. Chris listed three different levels (elementary, middle, and secondary levels) of questions that could be used to develop conceptual models of how cholesterol relates to blood pressure. d. Realized that modeling is beneficial of students as a means to learn new knowledge. e. More explicit intrinsic representation of blood was needed, perhaps by using red food coloring. f. Elementary teachers understand the purpose of the modeling experience g. Your model will never be complete.

KSUm	<ul style="list-style-type: none"> a. “when we put glue into the straw, what happened to the blood?” b. He used the answers from the elementary teachers as an anchor to explain how cholesterol functions c. asked questions such as “if we take the medicine, some of the medicine fence the clot...what is happening now?” d. “what’s the really bad food for?” e. That’s a good point. Blood clots move. They don’t just break apart all the time; they move throughout the body.’ And, a lot of them had never really thought about that; so that was pretty cool. f. the prospective elementary teachers observed how the water pushed glue away from the wall of the blood vessel (straw) during the modeling activity g. it was evident they could connect that blood clots could be moving in our body. h. it didn’t look realistic enough i. more explicit intrinsic representation of blood was needed, perhaps by using red food coloring. j. modeling activity was more structured, teachers would not be able to see students’ misconceptions and the activity would not be open to the model’s revision. k. Your model will never be complete.
KASm	<ul style="list-style-type: none"> a. modeling activity was more structured, teachers would not be able to see students’ misconceptions and the activity would not be open to the model’s revision.
KISm	<ul style="list-style-type: none"> a. You can make it as super simple as you want or very, very complicated b. how this modeling is a great visual representation of the blood clots and the blood pressure. c. realized that modeling is beneficial of students as a means to learn new knowledge. d. the power of analogical thinking through modeling in understanding a new phenomenon. e. the prospective elementary teachers observed how the water pushed glue away from the wall of the blood vessel (straw) during the modeling activity f. modeling strategy was effective and could be adjusted for many different developmental ages. g. more explicit intrinsic representation of blood was needed, perhaps by using red food coloring. h. it didn’t look realistic enough i. elementary teachers understand the purpose of the modeling experience j. your model will never be complete. k. stressed the importance of uncertainty in the modeling experience l. modeling activity was more structured, teachers would not be able to see students’ misconceptions and the activity would not be open to the

	model's revision.
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(a) Orientations toward science teaching using modeling (KOTm), (b) Knowledge about modeling in science curriculum (KSCm), (c) Knowledge of students' understanding of scientific modeling (KSUm), (d) Knowledge of assessment in science using modeling (KASm) and (e) Knowledge about instructional strategies in science using modeling (KISm)

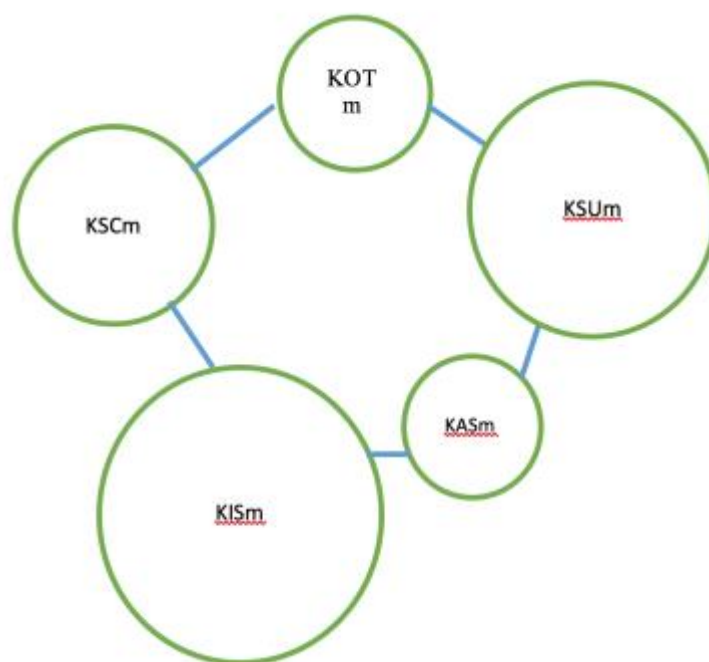


Figure 3.6 Chris' development of PCKm

Figure 3. 6 illustrates the relative development of PCKm components for Chris and Table 3.8 illustrates Chris' understanding of the interconnectedness of PCKm components.

Table 3.8 Chris' interconnectedness of PCKm components

Statement	KOTm	KSCm	KISm	KASm	KSUm
He realized that modeling is beneficial of students as a means to learn new knowledge.	√	√	√		
He used the answers from the elementary teachers as an anchor to explain how cholesterol functions		√			√
More explicit intrinsic representation of blood was needed, perhaps by using red food coloring		√	√		
"it didn't look realistic enough"			√		√
Chris listed three different levels (elementary, middle, and secondary levels) of questions that		√			√

could be used to develop conceptual models of how cholesterol relates to blood pressure.					
Modeling strategy was effective and could be adjusted for many different developmental ages.		√			√
Modeling activity was more structured, teachers would not be able to see students' misconceptions and the activity would not be open to the model's revision.			√	√	√
Elementary teachers understand the purpose of the modeling experience		√	√		
Your model will never be complete. Stressed the importance of uncertainty in the modeling experience		√	√		√
Modeling activity was more structured, teachers would not be able to see students' misconceptions and the activity would not be open to the model's revision.		√	√		
The prospective elementary teachers observed how the water pushed glue away from the wall of the blood vessel (straw) during the modeling activity			√		√

Summary

Examination of the three cases showed that the prospective teachers developed knowledge about instructional strategies in science using modeling (KISm) most commonly from among the components of PCKm. Secondly, the prospective teachers developed knowledge of students' understanding of modeling (KSUm) and knowledge about modeling in science curriculum (KSCm). Knowledge of teacher orientations was also occasionally a product of the modeling activity, but there was little evidence of knowledge of assessment in science using modeling (KASm) through the modeling mini-lesson implementation. Jodice's case demonstrated consistency with Park & Chen (2012)'s research finding with respect to the development of interconnectedness between KISm and KSUm. Denise's and Chris' cases added to that finding (though less strongly) that prospective teachers developed an understanding of the interconnectedness between KISm and KSCm. However, our findings are also consistent with Park & Chen (2012)'s finding that KIS was central among PCK that developed within teaching

activities for prospective teachers. In particular, it is meaningful to note that Chris' case showed that prospective teachers could develop a certain level of PCKm and an understanding of the interconnections among PCKm components through the modeling implementation experience even though it is probably best labeled as a type of Proto-PCK. PCK development has traditionally been shown in examples of teachers who are teaching students in long term classes assigned to them. However, identifying these units of proto-PCK marks is an important step in understanding how PCK emerges in teachers.

Discussion and Implications

Investigating prospective secondary science teachers' PCKm (pedagogical content knowledge of modeling) is a meaningful way to understand changes in their instructional practice as well as their future behaviors in science classrooms for which they are the assigned teacher. The *Next Generation Science Standards* (NGSS, 2013) promotes modeling practice and its inclusion throughout the entire K-12 science education spectrum. The preparation of prospective teachers in the enactment of modeling practices and its assessment is an important aspect of learning to teach science. It is well-documented that teachers teach students the way they themselves learned (Russell & Martin, 2014) and teachers' perspectives are rooted in guiding images from earlier experiences as pupils (Calderhead & Robson, 1991; Kagan, 1992). Thus, prospective teachers need to experience modeling practices by themselves and figure out how they develop, use and assess models, modeling practices, and meta-modeling knowledge in their future classrooms during their teacher preparation program. In this study, secondary prospective teachers were exposed to modeling experiences as their own learning activities and had opportunities to implement their lessons using models and modeling. Research has shown

that teacher knowledge is developed through experience, and teachers tend to learn from actual practice (Kagan, 1992). The research reported here is an example that documents how this teacher knowledge is developed. Our view of teacher knowledge and beliefs is aligned with another aspect of the work of Kagan (1992) and Pajares (1992) who asserted “belief as knowledge”. Pajares (1992) argued that, in many cases, it is not easy to pinpoint the boundaries between knowledge and belief because of the nature of teaching, teachers’ experiential and episodic knowledge (Pajares, 1992). Pajares (1992) cited Clandinin and Connelly (1987)’s quote, “embodied and reconstructed out of the narrative of a teacher’s life” (p. 490) to address this characteristic of teacher’s knowledge.

We recommend encouraging prospective teachers to incorporate modeling activities into their lesson/unit plans to establish a foothold to enact modeling practice in their instruction. We also suggest that the use of diverse forms of models, including games as a modeling strategy, can be an effective and creative way of teaching science and can broaden prospective teachers’ knowledge about instructional strategies using models. As Jodice used the marble game for modeling energy transfer and Denise’s group’s used the gesture game on the phase changes of water, the form of game is an effective way of constructing modeling strategy. These games might be adapted for instruction in the form of computer games or virtual simulations (e.g., MUVES).

In this study, prospective teachers also tried to use diverse forms of models to explain scientific phenomena. This use of diverse forms of models could enhance student learning, providing them with opportunities to develop deeper understanding of science concepts with different views (Shen & Confrey, 2007). Diverse forms of models are also beneficial for diverse learners.

Through the design experience of modeling-based instruction, we found prospective teachers' PCK of modeling (or at least proto-PCK) as an instructional strategy was developed and enhanced. The cases of the prospective teachers highlighted in this study imply many important things about science instruction. We see the importance of prospective teachers' awareness of students' ownership in their lessons. We learned that prospective teachers started to see the effectiveness of multimodal models in science instruction: the prospective teachers' awareness of game as an effective modeling tool, the usefulness of bodily movement in modeling activity, and the incorporation with lab activity for building new knowledge.

Finally, we learned that the prospective teachers developed PCK for modeling through implementation of modeling in the context of peer teaching. The prospective teachers' PCKm was developed mainly through insight into KISm, KSUm, and KSCm. But it is important to note that this study provides evidence that the prospective teachers recognized the interconnectedness among PCKm components. The findings with respect to the development of PCKm (even though it is a proto-type of PCK due to the prospective teachers' lack of experiences in teaching) imply the possibility of prospective teachers' development of PCKm during a teacher preparation course. This course is one of the first steps and is hopefully central to their professional lives. In this sense, prospective teachers' high quality learning experiences of modeling practice needs to be fostered in teacher preparation programs to construct the important knowledge base for future teachers.

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Appendix B. Prospective teachers' learning experiences on modeling in the teacher preparation program.

Session (time)	Objectives	Main activities	Questions for discussion
1.5 hours	To understand the participants' prior knowledge and beliefs about modeling and understand what the model and modeling in science are. To experience how modeling is used in classroom.	-Powerpoint presentation about models and modeling (30mins). -Hand modeling activity1: (individual) The researcher will show an initial hand model made with straws and fishing lines. Prospective teachers will be allowed to make the same model or similar models which function like a human hand. -Discussion: prospective teachers discuss about "what is represented in the hand model to explain hand anatomy?"	What is a scientific model? What are its main functions? How can a typology be used to describe the variety of models? What are models' strengths and limitations? How are modeling activities used in classroom? Why are modeling activities used in classroom? What is represented in the hand model? What are the differences and similarities between the human hand and the model hand? What are the strengths and weaknesses of a model?
2 hours	To understand how analogy is used in a model. To understand what the modeling process is occurred. To understand how modeling is used in design cycle.	- Hand modeling activity2: (collective) Based on the initial hand models were made in the previous class, prospective teachers are asked to design hand models to pick up big pieces of candy. -Discussion - Hand modeling activity3: (collective) Suppose that big pieces of candy has been extinct and only small pieces of candy are available for some reason. Now the prospective teachers are asked to revise their models that they made in the previous class to pick up small pieces of candy. -Discussion	What is the design cycle? How to revise a model? What role does modeling play in design process? How can we compare each model? What is adaptation? What are suitable models of adaptation? How to revise a model? What role does modeling play in design process? How can we compare each model? What is the modeling process?
2 hours	To understand how modeling is used in inquiry-based teaching.	-Inquiry about the grain size of the activated charcoal for purification. (collective): The relationship between the grain size of the activated charcoal and water flow rate. The relationship between the grain size of the activated charcoal and the degree of purification. -Model how the activated charcoal work for purification (e.g. drawings). -Presentation of models to class	How to design their own experiment? How can the models be built from the findings from experiment? How scientists build their models in scientific inquiry process? What role does a model have in scientific inquiry? How your data can be represented? What kinds of representations are suitable to describe your data? (e.g. graphs, diagrams, physical models, gestures, etc)

1.5 hours	<p>To understand scientific models change over time based on new evidences</p> <p>To understand how a model is tested in engineering design.</p> <p>To understand the role of models in communicating with others.</p>	<p>-Why scientists use models/modeling? (8 minutes videos and powerpoint presentation)</p> <p>-Water Purifier design activity: (collective)</p> <p>Prospective teachers will be asked to design water purifier for best water quality with given various consumable materials such as activated charcoal, cotton, pebbles, sand, filter papers, etc.</p> <p>-Model presentation: (each group 10 mins). Explaining how each system of water purifier works. Comparing each water purifier.</p> <p>-Peer Review during presentation.</p>	<p>What is a model in design activity? How is the modeling process in designing water purifier? What is the important modeling process in designing water purifier? How can be used a model to represent a system? What is the affordances and weaknesses in this modeling activity?</p> <p>How a model is used for communicating with others? Which models are good models? And why?</p>
1hour	To understand how modeling can be used in assessment for science learning.	<p>- Model assessment activity1: Allow prospective teachers to assess elementary students' models of condensation and evaporation from Schwartz et al. (2009) or plate tectonics from Gobert (2000). -Discussion about the rubrics for assessment of models.</p>	<p>What is a good model? How to use modeling in classroom assessment (e.g. diagnostic and formative assessment)? What components are needed in the rubric of model assessment? What kinds of criteria for the modeling assessment can be created?</p>
1hour	To understand how modeling can be used in assessment for science learning.	<p>-Modeling assessment activity2: Allow prospective teachers to assess 3D physical models or the process of modeling.</p> <p>-Discussion about the rubrics or criteria for 3D models and modeling process.</p>	<p>What is a good model? How to use modeling in classroom assessment (e.g. diagnostic and formative assessment)? What components are needed in the rubric of model assessment?</p>
2hour (20mins×6 groups)	To implement modeling instructions (mini-lessons).	<p>-Implementation of Modeling lessons: Allow prospective teachers to have opportunities of lesson plans and implement of modeling lessons to other method course students to introduce what modeling is. (20 minutes for each group). -Getting feedback about the lessons from peer students.</p>	<p>What is a good model? How to use modeling in classroom assessment (e.g. diagnostic and formative assessment)? What components are needed in the rubric of model assessment?</p>

CHAPTER 4

TEACHING PROSPECTIVE TEACHERS ABOUT MODELING-ORIENTED ASSESSMENT
AS A FORM OF AUTHENTIC ASSESSMENT OF SCIENCE LEARNING³

³ Kim, Y. and Oliver, J. S. To be submitted to *International Journal of Science Education*.

Abstract

This study examined the adaptation of knowledge about Modeling-Oriented Assessment by prospective science teachers into rubrics that are planned for use with future students. Data analysis showed that the prospective teachers also added new categories that were not originally included in the research related to MOA. The prospective teachers were not able to see benefit in the assessment of meta-modeling knowledge of future students. In addition, the prospective science teachers created ‘filters’ such as fairness related to grading that were powerful influences on the final form of the created rubric. This study showed the importance of experiences with modeling and opportunities for implementation of modeling in teacher education. By introducing MOA and authentic assessment into prospective teacher preparation courses, the knowledge of modeling can be enhanced with a comprehensive view of modeling. In addition, the study identified needs to support prospective teachers’ learning about assessment itself and meta-modeling knowledge in teacher education.

Introduction

Modeling in science classrooms is an active learning approach, which offers students the chance to describe, explain, and predict scientific ideas with multiple representations (NRC, 2012). The use of multiple representations means that the content is represented in a model that might take a variety of forms (e.g., drawings, diagrams, physical models, mathematical equations, computer simulations, etc.). Through modeling practice, students construct their own models and revise the models in response to new evidence and information, similar to what scientists do (Windschitl et al., 2008). In this respect, students’ ownership needs to be emphasized in modeling activities as active learning by creating opportunities for sense-making

talk (Windschitl et al., 2008). Modeling is a knowledge building tool (Schwarz et al., 2009) for students, even if student-generated models are not sophisticated (Gilbert, 2004) as compared to textbook explanations or scientists' models. However, in many cases, teachers use models and modeling activities for demonstrating and explaining scientific phenomena, and in my experience most modeling activities conducted are done by teachers. Therefore, students usually experience models in passive ways.

The new framework for K-12 science education (NRC, 2012) suggests developing and using models as one of the core practices of science and engineering practices. Also, the Next Generation Science Standards (NGSS Lead States, 2013) promote modeling throughout the entire K-12 science curriculum in science teaching. The emphasis on modeling as a scientific and engineering practice in the NGSS particularly emphasizes students' own active modeling processes and is referenced to the manner in which scientists and engineers build on current knowledge and solve a problem. "Models provide scientists and engineers with tools for thinking, to visualize and make sense of phenomena and experience, or to develop possible solutions to design problems" (Krajcik & Merritt, 2012, p. 10). The benefits of instruction using models (i.e., Modeling-based Instruction) in science classrooms were discussed in many studies, including authentic (Gilbert, 2004), inquiry-based (Krajcik & Merritt, 2012), active and collaborative learning (NRC, 2012; Quellmalz et al., 2012).

The promotion for teaching science with modeling practice as described in the NGSS signifies the importance of assessment using models and modeling in alignment with modeling-based instruction. This is based on the essential principle that assessment needs to be aligned with learning goals and instructions. In addition, students need to know how they are being assessed and what types of assessment are being utilized. Also, if teachers understand how to

assess models and modeling, they can provide valuable feedback about students' learning with models/modeling (Namdar & Shen, 2015). In this sense, teachers' knowledge about the assessment of student learning using models and modeling needs to be better understood.

In this paper, we describe prospective secondary science teachers' experiences with Modeling-Oriented Assessment (MOA) in a science methods course with a practicum. 'Modeling-Oriented Assessment (MOA)' was termed in Namdar and Shen's (2015) paper, meaning the assessment of knowledge, skills, and practices related to models and modeling. We highlight prospective teachers' struggles and tensions in the process of designing a rubric using modeling as part of a unit plan. This assignment to create a rubric was specifically designed to focus their work on MOA. In particular, we illustrate how the prospective teachers' knowledge of MOA developed over the course of their practicums and what knowledge of and beliefs about MOA evolved. During the practicums which are site-based school experience and consisted of class observations and co-teaching experiences with mentor teachers, the prospective teachers started to learn how schools function, how science classrooms look and how secondary students engage in science learning.

MOA as an authentic assessment

We start with the view that MOA is an authentic assessment for science learning. Authentic assessment is assessment involved in real-life or authentic tasks and contexts. Gulikers et al. (2004) defined *authentic assessment* as: "an assessment requiring students to use the same competencies, or combinations of knowledge, skills, and attitudes, that they need to apply in the criterion situation in professional life" (p. 69). Although there are different views about authenticity, it is agreed that the need for authentic assessment is found in its reflection of a real-life situation rather than the knowledge probes of traditional assessment. Darling-Hammond and

Snyder (2000) investigated how teacher education programs used authentic assessments as tools to support teacher learning. These authors addressed how authentic assessment tools help cooperating teachers and student teachers become more thoughtful about and enrich their own practices. In addition, authentic assessment emphasizes the consistency between learning and assessment (Guilker et al., 2004). “Learning and assessment are two sides of the same coin, and ...they strongly influence each other. To change student learning in the direction of competency development, authentic competency-based instruction aligned to authentic competency-based assessment is needed” (Guilker et al., 2004, p. 68). Since the NGSS emphasizes modeling practice in K- 12 science learning, modeling also needs to be used in the assessment of student learning outcomes. In classroom settings, teachers can determine how students’ understanding of scientific ideas is developed through modeling activities as students learn science. In addition, students learn modeling as a scientific practice in scientific inquiry processes when they are engaged in modeling activities. In this sense, teachers’ ideas of authenticity in MOA are directly related to the plans and implementations of the use of modeling and its assessment throughout the teaching of science with an integrated understanding of the process of instruction and assessment.

Gilbert (2004) asserted that instructional use of modeling creates routes to more authentic science education for students. He described the characteristics of more authentic science education as faithfully representing science processes and its social aspects, reflecting core elements of creativity, providing satisfactory explanations of phenomena in the world-as-experienced and being capable of underpinning technological solutions to human problems. Just as Gilbert (2004) indicated the characteristics of authenticity in modeling, those same traits can be reflected in assessments using models and modeling. If MOA is not practiced in an authentic

manner in both the teaching and learning in science classrooms, MOA cannot be fully implemented with fidelity in science classrooms. Namdar and Shen (2015) addressed this issue when they wrote, “modeling tasks can also serve as an authentic environment in which students develop and apply various scientific practices similar to what scientists do.” In this sense, MOA also has the potential to provide meaningful approaches to student learning and assessment, and as such can be considered a form of *authentic assessment* (Litchfield & Dempsey, 2015).

In recent years, researchers who have been working on issues related to instructional uses of modeling have created a new focus that includes model evaluation as well as modeling as a tool for assessment. For instance, Namdar and Shen (2015) have synthesized assessment using models and suggested a framework for which they coined the name “model oriented assessment” (MOA). Also in this line of work is the research of Papaevripidou, Nicolaou, and Constantinou (2014) who summarized four modeling concepts in science education: (a) an ability or a skill, (b) a practice, (c) a scientific process, or (d) an instructional approach. From this basis, they conceptualized modeling as a *competence*. Nicolaou and Constantinou (2014) defined modeling as “the ability to construct and improve a model” (p. 55). For example, the modeling skills that represent scientific ideas related to a specific phenomenon can be assessed. Louca and Zacharia (2008) gave an example that if there is an absence of interactions among components in a model, it could be translated into an absence of understanding of how the phenomenon/system functions. At the same time, students can learn how scientific ideas can be developed and changed in the form of models.

MOA and Teacher Knowledge

Numerous researchers have examined the reasons why so few modeling practices are evident in school science. The consensus suggests three main reasons: (1) teachers’ have limited

knowledge about models and modeling (Justi and Gilbert, 2002; Kenyon et al., 2011), (2) teachers lack understanding about students' uses of modeling as a complement to learning (van Driel and Verloop, 2002), and 3) a lack of high-quality curriculum materials to support the use of modeling (Kenyon et al., 2011). The first of these assertions illuminates the need for the development of an understanding about modeling as an effective instructional strategy to introduce to prospective teachers. The second assertion suggests that helping teachers to gain insight into what students do during modeling opens the door to using modeling as an assessment tool. Again, this understanding must begin with prospective science teachers. The third assertion calls for the support of curriculum development using modeling for teachers to be able to implement modeling effectively. We believe that a deeper understanding of modeling by teachers is associated with improved student learning in science and a teacher's understanding of modeling as an effective instructional strategy and as an assessment tool plays a key role in promoting students' knowledge building in science. In this study, we focus on the need for prospective teachers to acquire a better understanding of modeling. Given this emphasis on modeling instruction, prospective teachers need support to understand diverse instructional aspects of models/modeling. In addition, teachers need insight into how students understand models/modeling in school settings, as well as how to effectively implement modeling with the assessment of student learning in their classrooms. In order to scaffold alignment between curriculum, assessment, and learning theories (NRC, 2000), by introducing the MOA framework in teacher preparation programs, prospective teachers' understanding of models/modeling can be enhanced with a complete picture of modeling instruction.

However, few studies have been conducted to examine how teachers and prospective teachers understand and perceive MOA or modeling competence in relation to modeling

practices in science classrooms. Namdar and Shen's (2015) synthesis study of MOA also focused on K-12 levels, looking at how MOA was used with K-12 students as assessment. We will draw from the categories of MOA from Namdar and Shen's (2015) study for analyzing the data in this study to understand prospective teachers' knowledge of MOA.

Given the importance of modeling practice and MOA in science teaching, this research reports the results of a study determining how prospective secondary science teachers' understanding of MOA developed within a block of courses on secondary science instructional methods during which modeling and assessment were emphasized. Therefore, the purposes of this study are to explore how the prospective teachers developed knowledge about assessment using modeling in science classrooms as they learned about the MOA framework and to investigate how the prospective teachers viewed MOA as an assessment tool through their experience creating a rubric for assessing modeling.

The following questions guided our inquiry:

1. How do prospective secondary teachers (PSTs) develop understandings of MOA (Modeling-Oriented Assessment) as evidenced by the design of assessment rubrics?
2. What successes and challenges do PSTs experience when engaging in the design of assessment rubrics using MOA?

Theoretical Framework

Modeling-Based Instruction (MBI) in Science Education

Scientists practice and recognize modeling as an important research and knowledge building process. Scientists have long used modeling to investigate and explain natural phenomena (Buckley et al., 2004; Gilbert & Boutler, 2000; Gobert, 2000, Louca & Zacharia,

2012). Lehrer and Schauble (2006) described modeling, noting that “scientific ideas derive their power from the models that instantiate them, and theories change as a result of efforts to invent, revise, and stage competitions among models” (p. 371). In this paper, we adopt a broad definition of models: a model is a human construct used to describe, explain, predict, and communicate with others a referent, such as a natural phenomenon, an event, or an entity, and modeling is the total set of practices used to construct models (Shen, 2006). Students can integrate knowledge and skills through modeling practices (NRC, 2012). Lesh and Doerr (2003) described how modeling practices typically require students to integrate multiple forms of mathematics, rather than to simply apply a single solution procedure. During modeling, students employ planning, construction, interpretation, evaluation, and revision skills (Schwarz et al., 2009; Lesh et al., 2000). Also, students use different types of knowledge and cognitive strategies in modeling practices (Schwarz et al., 2009). Thus, modeling practice is considered a knowledge-building tool in science learning, since it is a way of understanding scientific concepts (Schwarz et al., 2009) as well as actively engaging in scientific practices by creating opportunities for students’ sense-making talk (Windschitl et al., 2008). Developing and using models in science instruction is not only an inquiry-based teaching approach but also an integrated learning approach (NRC, 2012).

Modeling Competence and Modeling-Oriented Assessment (MOA)

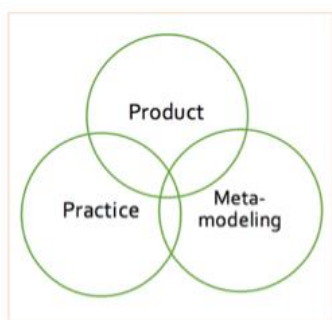


Figure 4.1 The three dimensions of MOA (Namdar & Shen, 2015)

Table 4.1 MOA Criteria in three dimensions

MOA Criteria (Namdar & Shen, 2015)
Assessment of Modeling Products
Quality of a Model Construct
Quality of a Model Representation
Coherence of a Model as a Whole
Assessment of Modeling Practices
Model Planning
Model Construction
Model Interpretation
Model Evaluation
Model Revision
Assessment of Meta-modeling Knowledge
Nature of Models
Nature of the Process of Modeling
Evaluation of Models
Purpose and Utility of Models

Namdar and Shen (2015) asserted that although students' modeling skills, knowledge, and products have been studied in multiple ways, assessments have mostly targeted students' content knowledge and/or affective domains. Building on the importance of aligning assessment with curriculum (Pellegrino, Chudowsky, & Glaser, 2001), designing assessments in a systematic way to capture students' learning gains through modeling has been encouraged (Van Borkulo, Van Joolingen, Savelsbergh, & de Jong, 2012). Namdar and Shen (2015) introduced the framework of MOA, which is defined as both a way to determine students' status with respect to variables of interest from a modeling perspective and a way to enhance student learning through modeling.

To capture these two criteria, MOA encompasses three dimensions: (a) assessment of student-generated models, (b) assessment of modeling knowledge and abilities demonstrated in modeling practices, and (c) assessment of meta-modeling knowledge. *Figure 1* shows the MOA framework and its three dimensions. Table 1 shows the criteria for inclusion into one of the three dimensions of MOA.

Authenticity in Modeling-Oriented Assessment

“Though the term ‘authentic’ has various value implications, authentic assessment broadly refers to an alignment between assessment tools and skills manifested within valued criterion situations. Stated differently, authentic assessment calls for assessments to align with the same skills that are needed in ‘real-world’ settings (Gulikers et al., 2004)” (Hathcoat et al., 2016, p. 893). Within the context of modeling, a real-world setting includes practices of what scientists do and competencies used by informed citizens to apply science to everyday life.

In this paper, ‘authentic assessment’ is based on Guilikers et al.’s (2004) view that assessment requires students to use similar knowledge, skills, and attitudes that reflect

competency in professional life. Authenticity in this paper is operationally defined in two ways: 1) similarity of task, context, knowledge and skills required for professional practices or real-life situations and 2) the alignment of assessment with instruction in which students are engaged. We hold the view that modeling-oriented assessment is an example of assessment of student learning with an authentic assessment tool.

Namdar and Shen (2015) discussed the authenticity of MOA in terms of “unit of analysis, assessment medium, and complexity” (p. 22). What they call “unit of analysis” refers to the unit of modeling activities they analyzed (collective/individual), and this is the same as Guilkers et al.’s (2004) concept of interaction form in the social context of the authentic assessment in their model. Namdar and Shen (2015) found, from a review of the literature on MOA, that the unit of analysis of most modeling practices was the individual. This finding points to a disjuncture given that collaboration is an essential feature of contemporary scientific practice and is promoted in many modeling studies (Gilbert & Boutler, 2000; Gobert & Pallant, 2004; Lehrer & Schauble, 2006). Thus in school science, means need to be found to assess collaborative modeling efforts among students as well as how to measure outcomes of collaborative modeling as an aligned component of assessment of instruction. In many cases, modeling-based instruction is conducted as a student group activity; therefore, student outcomes related to these learning experiences need to employ a form of modeling assessment that can also be implemented within a group context. In addition, Namdar and Shen (2015) illuminated a discrepancy between the media in which students engaged in their modeling activities and the media used for their assessments. For example, the authors addressed the issue that paper-and pencil are still a predominant means of assessing modeling even though most modeling activities depend on physical or computer-based materials. Finally, the authors examined issues related to the complexity of MOA as a tool for

assessing learning. Namdar and Shen (2015) put forward the three dimensions of MOA (modeling product, modeling practice, and meta-modeling knowledge), as a way of capturing the complex aspects of assessment of modeling practice and especially its process-based nature. For instance, modeling practices such as model construction, testing, interpretation, revision, and evaluation are interrelated and dynamic in nature.

We view the instructional uses of modeling as a means to learn science, learn about science, and learn how to do science. From the perspective of authentic assessment, assessment provides feedback on the learning process. Vu and Dall’Alba (2014) explained assessment as feedback in this way,

Learning for the future, including learning to become authentic, is a continuous process, which highlights a need for integrity and consistency of entire educational programs. Integration of assessment within a program can increase the clarity of what is expected of students in a consistent way, so as to direct them to appropriate learning and engagement in the opportunities provided to them. In addition, when assessment is integrated with the learning in which students are engaged, it can be used in providing timely feedback and assistance for student learning. (Vu and Dall’Alba, 2014, p. 788)

In this sense, thinking about the MOA as feedback for continuing learning fits with and is meaningful to the notion of authentic assessment in that students can be engaged in modeling as a scientific practice similar to what scientists do and construct their scientific knowledge through modeling and at the same time, be provided a valuable feedback to their learning and modeling process. As Namdar and Shen (2015) noted, the discussion about the connections between MOA items and the essential aspects of modeling to be assessed is immensely important in relation to learning goals. MOA as an authentic assessment becomes possible when teachers

recognize levels of tasks for assessment of modeling and how much scaffolding should be needed to support student progression between these levels. They suggested that the essence of modeling is found in the assessment of meta-modeling knowledge of specific aspects of modeling or the cognitive strategies related to modeling. Namdar and Shen (2015) recognized that other scholars have different views about what the essence of modeling is.

Modeling in Science Teacher Preparation Programs

The importance of models and modeling has been emphasized in science teacher education as well as in science (Justi & Gilbert, 2002; Gilbert & Boulter, 2000; Halloun, 2007). Teachers need to modify the scientific models into forms that make them more accessible so that students are able to understand these representations of scientific phenomena, concepts, or designed systems (Crawford & Cullin, 2004; Quellmaz et al., 2012). Also, the use of multiple representations and transformations of subject matter knowledge in science classrooms can be directly connected to the teacher professionalism (Park and Oliver, 2008). In this sense, prospective teachers' knowledge of scientific modeling is important as a component of their knowledge for teaching science.

In particular, teachers need to understand how to align instructional activities that include modeling to learning objectives and then assess students' learning with modeling, as well as whether these activities are effective for meeting those objectives. These forms of knowledge are also required for prospective teachers. Kenyon, Davis, & Hug (2011) addressed, "the supports for developing PCK for scientific modeling and considering modeling across science content areas are critical for helping prospective teachers consider modeling in multiple contexts" (p.17).

Nelson and Davis (2011) conducted a study on prospective elementary teachers' ideas about scientific model evaluation. The authors extracted categories that prospective elementary

teachers thought important in evaluating models when they tried to evaluate elementary student-generated models on evaporation and condensation in a solar still and germ transmission. Nelson and Davis (2011) identified seven main model evaluation criteria: sense-making, communication, consistency with evidence, aesthetics and features, generativity, mechanism or process, and terminology (p. 1940). In this study, we will also refer to the categories in Nelson and Davis' (2011) study to build a conceptual model for a comprehensive framework of assessment using models/modeling leaning more toward the three dimensions of MOA from Namdar and Shen's (2015) research. Nelson & Davis (2011)'s findings, however, are mostly focused on evaluation of the model which is the Modeling Product in MOA. Therefore, we decided to use the MOA framework as a basis of data analysis which is relatively comprehensive, covering modeling product, process, and meta-modeling. Also, we expected to investigate PSTs' responses and emerging ideas to the three MOA dimensions which was stressed in the methods course.

Procedure

The data collection for this qualitative study was conducted at a southeastern state university in the US in the fall of 2015. The secondary science prospective teachers were taking an instructional methods course as a component of their degree/certification requirements. It was the last year of their program leading to secondary science certification. Their experience included a school-based practicum, through which they had started to learn how schools function, how to interact with secondary students and how to teach science in a classroom setting with students. The curriculum of the secondary science methods courses included: major learning theories, inquiry based learning, science standards, designing lesson plans as well as assessment.

In this methods course, there was a diverse group of students in terms of majors (physics, chemistry, earth science, and biology). A majority of these students were majoring in biology. There were approximately equal numbers of male and female students as well as numbers of students enrolled in master's or undergraduate programs.

In the fall of 2015, the secondary science methods course emphasized modeling practice as described by the eight scientific and engineering practices of the NGSS (NGSS Lead States, 2013). In the methods course, prospective teachers learned about modeling practice, including modeling-based inquiry, modeling-based reasoning, and modeling practice in science and engineering. Also, the prospective teachers participated in discussions about the important criteria for the modeling-based assessment. This part of their instruction included some examples. The prospective teachers were asked to create an assessment rubric based on what they had learned about the important components of modeling that should be reflected in the prospective teachers learning (or that of future students). Finally, creating the assessment rubric for modeling was part of a curriculum unit plan so that the prospective teachers could see how that aspect of assessment fit in the larger picture of a unit. The prospective teachers selected their own topic for the curriculum unit and for the assessment rubric. Creating the assessment rubric for modeling was designed for not only developing ideas about instructional design using modeling by selecting a lesson which works well with modeling (Kenyon et al., 2011), but also aligning their lessons using modeling with assessment practice.

The following data sources were used by the researchers: the modeling-oriented assessment rubric, prospective teachers' reflection on the rubric, and semi-structured interviews. Reflection on the rubric occurred as prospective teachers created the rubric. So, the assignment consisted of two parts, rubric and reflection on creating the rubric. They submitted these

documents as one assignment at the same time.

At the beginning of semester, we conducted an open-ended survey on modeling as part of an effort to understand the prospective teachers' prior knowledge of modeling. The primary purpose of this survey was to guide participant selection from among the volunteers in the course. Sample questions included: 'Describe any *formal/informal* experiences you have with models/modeling', 'Describe what you think is a good example of models/modeling. Explain why.' and 'In a science classroom, what do you think are the strengths and weaknesses of modeling?'. From among the pool of volunteer participants, and seeking to enlist a sample of maximum variance, five participants were selected for the study. During the semester, all the prospective teachers experienced modeling activities on four occasions and were assigned modeling-related readings. The prospective teachers were provided an opportunity to discuss how to assess student-generated models and consider the important criteria in assessment of models. As an example, Gobert's (2000) article in which students' model the interior of the earth, and its causal and dynamic processes was discussed. Then, the prospective teachers were introduced to the Modeling-Oriented Assessment (MOA) framework. As was stated earlier, the MOA framework from Namdar & Shen (2015) has three dimensions containing those criteria of what to assess in models and modeling. The reason why we used the MOA framework in teaching and as an analytic tool is that the three dimensions and criteria in MOA framework provide a comprehensive tool for the prospective teachers to think about assessment using models and modeling. This MOA framework is also used with the hope that the prospective teachers can see multiple perspectives on models and consider three dimensions of MOA as significant areas of assessment. After their MOA introduction, the prospective teachers were asked to create a rubric using modeling as a part of their unit plans. When the prospective

teachers submitted a rubric, they also wrote a reflection on the rubric they created. At the end of semester, the prospective teachers had an opportunity to implement modeling mini-lessons in another science methods course for prospective teachers of elementary level science.

During the semester, three semi-structured interviews were conducted with the five participants. The first interview was focused on the prospective teachers' general ideas about modeling. The second interview was mostly focused on the prospective teachers' understanding of MOA. The third interview was focused on the prospective teachers' experience with modeling mini-lessons. Sample items from the three interviews are shown in *Appendix C*. *Figure 2* shows the timeline within the semester for the data collection activities.

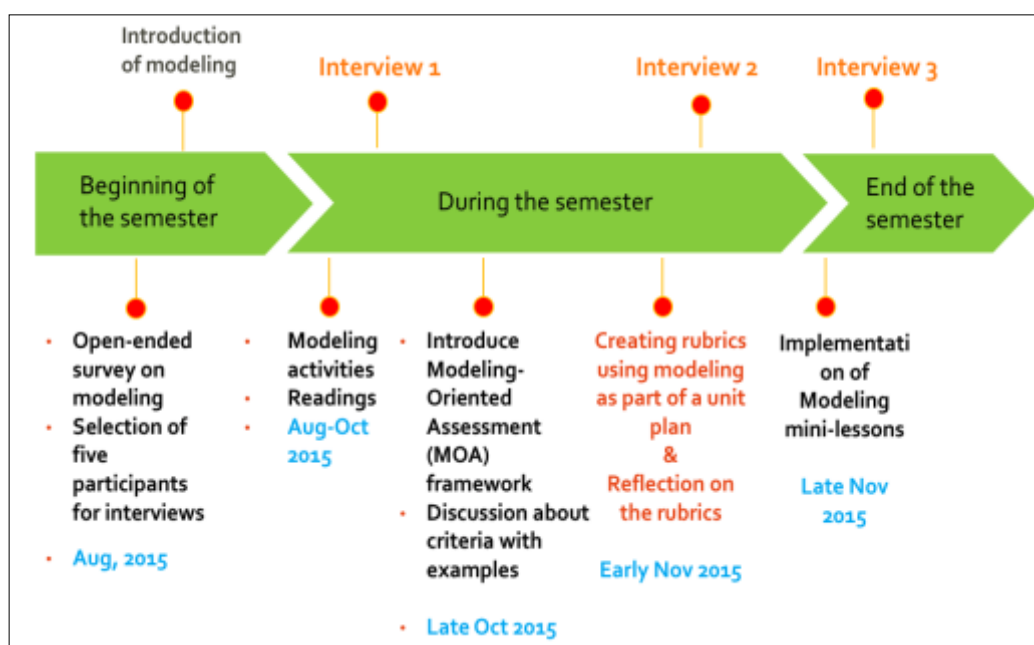


Figure 4.2 Timeline for the study

Among the prospective teachers, who volunteered as research participants, only one was majoring in chemistry and eleven were biology majors. We selected five participants with a maximum variance in content area, major, lab experience, and gender. Lab experience refers to

whether the participant had experience as a laboratory teaching assistant.

Table 4.2 Participants information: five secondary science prospective teachers who were taking an instructional methods course with a school-based practicum.

	Chris	Allis	Shannon	Denise	Jodice
Content	Biology	Biology	Biology	Chemistry	Biology
Major	MAT	BSEd	BSEd	MAT	MAT
Lab experience	Yes	No	No	Yes	No
Gender	Male	Female	Female	Female	Male
Topic in the assessment rubric using modeling	How infectious disease spread in a community and within a population	Phylogenetic tree as a model and modeling hominid	Photosynthesis and cellular respiration	Valence electrons and unpaired electrons	Nature of adaptations natural selection by building their own bird beaks

Data Analysis

This study employs a qualitative case study approach. Simons (2009) stated, a case study aims “to present a rich portrayal of a single setting to inform practice, establish the value of the case and/or add to knowledge of a specific topic” (p. 24). Also, Patton (2002) described the purpose of a case study is “to gather comprehensive, systematic, and in-depth information about each case of interest” (p. 447). If a researcher wants to do a case study, commonly, the results include thick and in-depth descriptions of specific people, topics, issues, programs, and events through close examinations (Hays, 2004). In other words, the most important feature of case study research is to understand human experiences and contexts around human phenomena more deeply.

Thus, in case study research, contexts and situations are important. By examining and interpreting a case in-depth through diverse lenses, a case study is broadening our understandings about a phenomenon of interest (Baxter & Jack, 2008). Yin (1989) stated that case studies are

needed to understand complex social phenomena, and researchers can do investigations to retain holistic and meaningful characteristics of real-life events (p. 14). Also, this study took place in educational settings which researchers cannot manipulate the behavior of those involved in the study (Yin, 2003). We view the characteristics of a case study for describing a phenomenon in depth ultimately inform educational practices through this study.

In this study, we examined the prospective teachers' development of understanding of the assessment of student learning outcomes with modeling when modeling was incorporated as a component of instruction and assessment, in particular, how prospective secondary teachers develop understandings of MOA (Modeling-Oriented Assessment) by the design of assessment rubrics.

The goals of this study are focused on understanding how prospective secondary teachers develop their knowledge about modeling and MOA. All prospective teachers in the course were exposed to the same modeling activities, but each participant was able to focus on a different aspect of modeling and MOA. In fact, the findings showed each participant developed different understandings of modeling and MOA through the creation of MOA rubric. We believe that this study helped us to generate understandings about how the prospective teachers' prior experiences, context, and situations in-depth influenced teacher knowledge and beliefs, and ultimately their practices.

In this study, the data sources include: assessment rubrics, reflections on rubrics, and interview transcripts. The class periods in which the prospective teachers participated in modeling were observed by the researchers and field notes were recorded from these observations. For this component of the research, the primary data source is the assessment rubrics that the prospective teachers created. As was stated previously, the assessment rubrics

were created after the prospective teachers received instruction on modeling and thus were based on their understanding of modeling both from their original “pre” conceptions as well as new learning. In the rubrics, the prospective teachers created criteria that they thought included the essential features to consider when assessing modeling. The prospective teachers also wrote reflections and rationales on their criteria they used in developing the rubrics. Data from rubrics, reflections, and interview transcripts were coded to obtain insight into the prospective teachers’ use of MOA criteria presented in the methods course, as well as emergent MOA criteria.

During the coding process, a labeling system was created in order to easily differentiate the MOA dimensions and criteria. To illustrate the use of this system consider the first dimension of the MOA criteria (Namdar and Shen, 2015). Under the first dimension, “Assessment of Modeling Products”, there are three criteria: quality of a model construct, quality of a model representation, and coherence of a model as a whole. In the coding scheme, these criteria are coded as: PROD: Construct; PROD: Representation; and PROD: Coherence. This system was used throughout the analysis of the MOA criteria and included labels of this type for any aspects of the MOA model that were included by participants and NOT included by Namdar and Shen (2015).

As introduced above, Namdar and Shen (2015)’s MOA framework has three dimensions: *Assessment of Modeling Product (PROD-)*, *Assessment of Modeling Practice (PRAC-)*, and *Assessment of Meta-Modeling Knowledge (META-)*. Assessment of modeling product (PROD-) means assessing a student’s modeling product which is a model itself. Assessment of Modeling Practice (PRAC-) means assessing a student’s modeling practice in the real-time modeling process, and Assessment of Meta-Modeling Knowledge (META-) refers to assessing a student’s knowledge of models and modeling (e.g. the nature and purpose of models).

The analysis of the first dimension, the PSTs' assessment of modeling product (PROD-) revealed four themes: PROD-construct (quality of model construct), PROD-representation (quality of model representation), PROD-coherence (coherence of a model as a whole product), and PROD-presentation (quality of model presentation). The second dimension of MOA, the PSTs' assessment of modeling practice (PRAC-) highlighted six modeling practices in the modeling process: PRAC-plan, PRAC-generation, PRAC-revision, PRAC-interpretation, PRAC-evaluation, and PRAC-collaboration. Finally, the third dimension, assessment of meta-modeling knowledge (META-) means explicitly assessing students' understanding of the nature of models and modeling. The assessment of meta-modeling knowledge (META-) included four components: META-model (nature of models), META-modeling (nature of modeling), META-evaluation (evaluation of models), and META-purpose (purpose or utility of models). Initially Namdar & Shen (2015) adopted the categories of assessment of meta-modeling knowledge (META-) from Schwarz & White (2005)'s work. We then identified the criteria consistent with Namdar & Shen (2015)'s criteria of meta-modeling knowledge (META-).

These three dimensions of MOA are separated here for analytic purpose. In reality, all three dimensions are closely interconnected and integrated (Namdar & Shen, 2015). For example, meta-modeling knowledge can guide modeling practice in the process of model construction and it influences the quality of models. However, we separated the three MOA dimensions for analysis, and analyzed PSTs' recognition of the interconnectedness of components of three MOA dimensions later.

In this study, we used theoretical thematic analysis (Braun & Clarke, 2006). First of all, the researchers familiarized themselves with the three MOA dimensions (Namdar & Shen, 2015). At the first level of coding, the researchers open-coded and generated initial codes of

prospective teachers' criteria of MOA inductively. During the second level of coding, we tried to categorize the codes. We sorted out similar codes and compared them with the categories of MOA dimensions. We categorized codes based on the MOA framework, looking at how each code reflected the criteria in the MOA framework. And, we identified what codes were similar to and different from MOA categories. If there were emerging categories which were not included in MOA dimensions, we identified new categories. At the third level of analysis, we examined the relationship among categories and codes, and generated primary themes. Generating themes is really a back and forth process in which the coder's attention moves between the data and the themes. As a final step, we reviewed and refined all the themes, and produced preliminary (inductive) themes. The process described above was the same in within case analysis and cross-case analysis.

For example, the prospective teachers were recommended to consider examples of student-generated models from the research article of Gobert (2000) on volcanic eruption and earth structure. Based on a discussion about possible criteria used in assessing models, the prospective teachers realized that a model's communicative features are as important as, the model content in MOA because clear expressions in drawings, physical models and explanations are the basis of what teachers can assess in models. Some of the student-generated models were hard to recognize what elementary students drew and represented in. Based on the data, we generated a code, quality of model presentation (PROD-presentation) for the modeling product (PROD-) dimension.

From analysis, we found many filters were in operation by the prospective teachers when creating rubrics for future use of models. The data analysis revealed filters such as fairness, authenticity, forms of model, purpose of assessment, etc. A 'filter' is defined as a consideration

employed by a (prospective) teacher to identify concerns when s/he attempts to assess MOA. Thus, a filter is characterized based on an awareness of what we need to consider when we assess models and modeling. And, we assume that the filter influences the (prospective) teachers' decision-making about what will be included not as criteria, or what level of and what portions of assessment will be done in assessment. The reflections of PSTs described a rationale for why they chose and excluded the criteria in their rubrics of MOA. In the rationale and in probing interviews, PSTs addressed the considerations and challenges in creating MOA rubrics, so we coded the considerations as filters. We coded each filter on a spectrum based on analysis of how much the participant considered the filter in the structure of the assessment rubric, and how influential the filter was within the case. For instance, when a participant selected 'aesthetical ability' as a filter in the consideration of what can be fairer in grading, the 'aesthetical ability' was coded as a filter within 'fairness' section. Then, when we coded it on a spectrum depending on how 'aesthetical ability' is considered and reflected to his/her rubric. (*Refer to Figure 4.4*).

In cross-case analysis, we compared each filter among cases. The influential filter was different in each case. We coded each filter for each case when the filter was emergent in reflection or interviews. If there was no evidence of a filter in a case, we did not include it on the spectrum.

When we analyzed interconnectedness among categories, we coded if there were explicit expressions of interconnectedness in cases. A few interconnectedness of MOA criteria were emerged, then we created a circle graph to represent theoretical interconnections among MOA criteria (with dash lines in the graph), then put the real connections as a line from data. (*Refer to Figure 4.6.*)

Findings

The findings are divided into three major parts. First we will discuss general trends of PSTs' responses to MOA as an introduction in PART I. Then, we will describe assessment criteria which PSTs generated in their rubrics, including pre-existing criteria in the MOA framework and emerging criteria. Also, in this part, we examine how the PSTs created assessment criteria in relation to MOA three dimensions. In PART II, we illustrate case narratives which are representative of the research participants. Finally, we describe the themes from cross-case analysis in PART III.

PART I

PSTs' responses to MOA

PSTs' unfamiliarity with modeling

At the beginning of the course, the prospective teachers were not familiar with the more general idea of modeling although a few had previously encountered modeling. The prospective teachers' experiences with modeling were typically limited to a form of project that had required them to build a model in their schooling. None of the five participants expressed understanding of modeling as described by scholars and thus had little knowledge of the four major activities typically included in modeling: 1) scientific practice, 2) instructional strategy, 3) assessment tool, and 4) an object of assessment.

PSTs' growth of knowledge in modeling

As the prospective teachers experienced the modeling activities and modeling assessment in the course, they started becoming familiar with what a model and modeling are, modeling as a scientific practice, as well as modeling as an instructional strategy and an assessment tool. By the

end of semester, the participants were generally able to recognize modeling as an effective tool for assessing understanding of scientific concepts. They reported that this new knowledge of how to use models as assessment resulted from their introduction to the MOA framework (Namdar & Shen, 2015). Further the participants developed knowledge of assessment of models, modeling, and meta-modeling knowledge (we will show the related data in case narratives later). They felt that they had experienced significant growth in their individual understanding of modeling and MOA compared to their knowledge level prior to taking the methods course. In particular, many prospective teachers responded that they have previously never thought that models or modeling could be assessed. *Table 4.3* shows the summary of the five prospective teachers' assessment rubrics using modeling and how they approached MOA in relation to their instructions.

Table 4.3 Summary of Participants Assessment Rubrics

	Purpose of assessment	Forms of assessment	Purpose of assessment	Group	Topic
Denise	Understanding of concepts	2D and 3D models, written description	Formative	Group	Valence electrons and unpaired electrons
Jodice	Understanding of concepts & dealing with misconceptions	3D physical model essay	Summative	Individual Group	Nature of adaptations natural selection by building their own bird beaks
Chris	Understanding how each variable is involved	SIR computer model (digital graph)	Diagnostic Formative Summative	Individual Group	How infectious disease spread in a community and within a population
Allis	Modeling practice and model product	Forming of a scientific hypothesis 3D physical model & essay	Formative Summative	Group	Human evolution
Shannon	Developing and revising their models	2D drawing	Formative Summative	Individual	Photosynthesis and cellular respiration

Through the activity on modeling assessment and the assignment of creating a rubric for the purpose of assessing their future students' modeling, we found the prospective teachers planned MOA mostly focused on assessing scientific concepts through modeling rather than

evaluating a particular model itself, modeling process or meta-modeling knowledge. All five participants explicitly expressed that they wanted to assess the degree to which their students' models correctly represented the science content/concepts that define the end goals of student understanding. However, the participants' focus was mostly not on how the model represents the target, but rather concerned with content representation within the model itself. This means that models and modeling were considered by participants as a tool to teach mainly scientific content/concepts in the curriculum.

In fact, the participants also created criteria for inclusion in their rubrics that were not included in Namdar and Shen's (2015) MOA framework. For example, all five participants included 'collaboration' as a criterion in their modeling assessment rubrics usually identified with activities such as 'teamwork' or 'participation'. 'Collaboration' is not, however, among the original MOA dimensions. Therefore, the data analysis process resulted in the addition of new categories including PROD-Presentation, PRAC-Revision, and PRAC-Collaboration into the Namdar & Shen (2015)'s MOA categories (Green coded in *Table 4.4*).

Table 4.4 Categorization of PSTs' criteria of MOA: Adapted from MOA framework (Namdar & Shen, 2015) - Green colored codes are newly added categories.

Categories	Code	Sub-categories
Assessment of modeling products		
Quality of model construct	PROD – Construct	Model components
Quality of model representation	PROD – Representation	Attributions of components, Model content, reasoning, mapping, accuracy of model
Coherence of a model as a whole	PROD – Coherence	Reflect on real-life phenomena
Presentation	PROD – Presentation	Aesthetics, labels, Presentation & communication
Assessment of modeling practices		
Model planning	PRAC – Planning	Propose a justified and efficient plan
Model Generation	PRAC – Generation	Model construction, adding, selecting, testing
Model Interpretation	PRAC – Interpretation	Describing, explaining, and critiquing a model
Model Evaluation	PRAC – Evaluation	Comparing multiple models
Model Revision	PRAC – Revision	Model revision process
Collaboration	PRAC – Collaboration	Teamwork, Participation, & checkpoints
Assessment of meta-modeling knowledge		
Nature of Models	META – Model	Types of models and attributes, content, multiplicity
Nature of Process of Modeling	META – Modeling	Modeling process, changing nature of models
Evaluation of Models	META – Evaluation	way to decide one model is better than other, criteria
Purpose and Utility of Models	META – Purpose	Purposes and utility of models, use of multiple models

In this categorization process, careful examination and interpretation were needed when the prospective teachers use different language than MOA language originally described by Namdar and Shen (2015). For example, the prospective teachers created ‘aesthetics and features’ such as neatness, arrows, or labels for clear communication which is one of the roles of models. Then, we generated a new categorization of PSTs’ criteria of MOA adapted from Namdar & Shen (2015)’s categorization. *Table 4* shows the new categorization of PSTs’ criteria of MOA.

PSTs’ MOA criteria

Table 4.5 shows the specific criteria included by the prospective teachers as they created their MOA rubrics. If a criterion was coded in an assessment rubric its occurrence would not be duplicated in the table due to its repeated appearance in the analysis of the written reflection. It was felt that this was a valid procedure because the reflection is the explanation of the criteria. However, a statement appearing in the reflection which did not appear in the initial rubric was included in *Table 4.5* because it did not create a duplicate. In the interview transcript, the same principle was applied. For example, one prospective teacher created ‘model revision’ as an assessment criteria and wrote about the explanation of the criteria. Then, she mentioned about ‘model revision’ in her interview, and the researchers coded as one code ‘model revision’ as one criteria so that the code could not be over-coded since the explanation of the same code was represented in both the reflection and interview. However, if a new criterion emerged during the interview, we coded it as one criteria even though it was not included in the rubric.

In *Table 4.5*, we counted a kind of criteria as one code to look at the general trend in the data. However, detailed descriptions will be illustrated in each case to understand in depth how and why the prospective teachers included the criteria or not in their rubrics. *Table 4.5* indicated

that all participants attempted to assess understanding of concepts through modeling. Among the three dimensions of MOA, the participants most attempted to assess Modeling Product (PROD-).

Table 4.5 Analysis of PSTs' MOA criteria based on MOA framework (Namdar & Shen, 2015)

PSTs		Modeling Product				Modeling Practice						Meta-Modeling Knowledge			
	Understanding of Concepts	PROD-construct	PROD-representation	PROD-coherence	PROD-presentation	PRAC-plan	PRAC-generation	PRAC-revision	PRAC-interpretation	PRAC-evaluation	PRAC-collaboration	META-model	META-modeling	META-evaluation	META-purpose
Denise	1	1	3		1						1				
Jodice	1	1	1				1				1	1			1
Chris	1	3	1	1	2					1	2				
Allis	1	1	4		2			2			1				
Shannon	1	1	2		2			1			2				1
Total	5	7	9	1	7	0	1	3	0	1	7	1	0	0	2

In other words, among Modeling Product (PROD-), Modeling Practice (PRAC-), and Meta-Modeling Knowledge (META-), the prospective teachers tried to assess Modeling Product (PROD-), the model itself through modeling activities. Secondly the participants included the assessment of Modeling Practice (PRAC-) in their rubrics. But within modeling practice, the PSTs didn't attempt to assess model planning (PRAC-plan) and model interpretation (PRAC-interpretation). All the participants included collaboration (PRAC-collaboration) in the modeling process as a criterion in assessing modeling practice. In assessment of Meta-modeling knowledge (META-), PSTs attempted to create very few criteria. There were missing criteria in the criteria of both Modeling Practice (PRAC-) and Meta-Modeling Knowledge (META-).

In the following sections, the PSTs' assessment criteria of MOA will be described. Assessment of understanding of science concepts and all of the three dimensions of MOA

(PROD-, PRAC- and META-) are presented separately; missing criteria in MOA will be discussed in the remainder of PART I.

Assessment of understanding of concepts

From the analysis of prospective teachers' model evaluation rubrics, we first found that all five participants included criterion to assess understanding of science concepts through modeling. Each of the prospective teachers included 'understanding of concepts' in their rubrics as a criterion through which models could be evaluated. This finding is consistent with Namdar and Shen (2015)'s synthesis study on MOA. From the research articles about MOA used in K-12 education, the authors found that assessment of understanding of science concepts was frequently attempted by teachers whose instruction included student-generated models or modeling process. In this study, we found that the prospective teachers developed an understanding of how they might assess students' understanding of scientific concepts through modeling activities. Beyond this type of assessment, most prospective teachers also included within their rubrics criteria related to the accuracy of the model in relation to what the model represented as well as the correct grasp of scientific concepts resulting from modeling activities.

Assessment of modeling product (PROD-)

All of the participants included criteria in their rubrics regarding assessment of students' modeling product (PROD-). In general, the rubrics created by the prospective teachers contained the largest number of evaluation criteria with regard to modeling product (PROD-). Among these criteria, the prospective teachers planned their rubrics to assess the student's representation of content (PRAC-representation) within the model. This emphasis on model representation means that the prospective teachers paid attention to the model's role in explaining and describing scientific phenomena. The quality of model representation depends on the correctness and

completeness of representations in a model (Namdar & Shen, 2015). The criteria of quality of model construction (PROD-construct) was included in the rubrics by many of the participants who felt that it was a means to assess the quality, quantity, characteristics, and connections of the components of a model (Namdar & Shen, 2015). PROD-construct used to assess whether a model contains relevant components that are considered necessary by experts to represent structural connections in a system to be modeled (e.g. necessary model elements, number of variables and their relationship). Therefore, in model construction, we can assess correct names for model elements, the number of and types of variables involved, and the relationship among these variables.

Interestingly, the prospective teachers were also focused on the model's communicative features as aspects of their rubrics. Communicative features included aesthetic appeal, appearance of graphs, clarity or neatness in presentation of models. This finding is consistent with Nelson and Davis (2012)'s identification of, 'communication', and 'aesthetics and features' among model evaluation criteria. We define 'model presentation (PROD-presentation)' as how a model is presented for clear communications with others.

Finally, there was coherence of a model (PROD-coherence) as a criterion including in the rubrics for evaluating modeling products. This was much less commonly included in the rubrics than the criteria previously listed above. The coherence of a model (PROD-coherence) comes as a result of examination of those criteria used to assess how well a model reflects the real-world phenomenon (Namdar & Shen, 2015). Only Chris tried to assess coherence of a model (PROD-coherence).

Assessment of modeling practice (PRAC-)

Few participants included criteria in their rubrics regarding assessment of students' modeling practice (PRAC-). Within the modeling practice (PRAC-) dimension, there are PRAC-plan, PRAC-generation, The PRAC-revision, The PRAC-interpretation, and PRAC-evaluation categories. The PRAC-plan is a category within the "modeling practice" aspect of the rubrics that is used to assess the quality of modeling planning. Model planning might be exemplified by activities such as proposing a justification or creating an efficient plan for a model. The PRAC-generation is a criterion used to assess the quality of model generation including model construction and testing. The PRAC-revision used to assess the quality of model revision such as changing model parts, relationships, and modifying and improving a model based on testing. The PRAC-interpretation is used to assess the quality of model interpretation such as how students discuss, comment on model properties and describe, explain, and critique a model. The PRAC-evaluation is to assess the quality of model evaluation. The difference between model interpretation (PRAC-interpretation) and model evaluation (PRAC-evaluation) is that model interpretation (PRAC-interpretation) is a sense-making process of a presented model, but model evaluation (PRAC-evaluation) is rather a reflection process of assigning values and judgment to the model (e.g., good or bad, etc.) In many cases, model evaluation is being done among multiple models. These two criteria are closely related to meta-modeling knowledge. So PRAC-interpretation is basically having students talk about what the model is about; and PRAC-evaluation is having students talk about what are the strengths and weaknesses of a model (among many). It is important to note that PRAC-interpretation and PRAC-evaluation have some overlaps because one can't judge/evaluate without understanding/being able to interpret; also, oftentimes, we interpret a model and assign values/judgments at the same time. In the PRAC-

plan, PRAC-interpretation, and PRAC-evaluation, the prospective teachers rarely used these criteria. None of the participants attempted to assess these criteria.

In the aspect of helping the prospective teachers understand model evaluation we modified the modeling practice categories, from Namdar & Shen (2015). First, we added model revision (PRAC-revision) as an independent category which was initially included in the category, model generation (PRAC-generation) of the original MOA. We separated model revision (PRAC-revision) from model generation (PRAC-generation) because, although model revision can be considered a part of model generation by testing a model, the data analysis showed that the participants' actions included putting great emphasis on and having an independent criteria for the model revision process. Further, we separated the model revision category to highlight the prospective teachers' knowledge of assessment of model revision.

One more additional category that was not mentioned by Namdar and Shen (2015) was also included as a result of the data analysis. We labeled this category as "collaboration in the modeling process" (PRAC-collaboration). Every participant created a criterion within their rubrics that fit our definition of collaboration. The PRAC-collaboration is to assess the quality of collaboration in the process of modeling such as reflecting peer feedback on model revision to improve models, teamwork for constructing a group model as well as creating a consensus model as a group or whole class.

Assessment of meta-modeling knowledge (META-)

In general, the rubrics created by the prospective teachers contained the smallest number of evaluation criteria with regard to meta-modeling knowledge (META-). Within the assessment of meta-modeling knowledge (META-), four components exist: META-model (nature of models), META-modeling (nature of modeling), META-evaluation (evaluation of models), and

META-purpose (purpose or utility of models). Meta-modeling knowledge is knowledge about the nature and purpose of scientific models and modeling (Schwarz & White, 2005). The meta-modeling knowledge can be a personal insight into the one's knowledge about the nature and purpose of scientific modeling. For example, the idea that a model has a changing nature based on new evidence or has limitations in representing what is to be modeled.

With respect to assessment of students' meta-modeling knowledge (META-), the prospective teachers rarely planned to assess students' meta-modeling knowledge. In fact, some prospective teachers didn't feel it was necessary to assess students' meta-modeling knowledge. Only two prospective teachers (Jodice and Shannon) included criteria in meta-modeling knowledge (META-).

In Jodice and Shannon's cases, they included the assessment of students' meta-modeling knowledge through written formats (written essay or written rationale); however, they had few criteria and allotted only a small proportion of the total score to this aspect of the rubric. This may be because many prospective teachers did not have enough understanding of meta-modeling knowledge. Two of the participants (Chris and Denise) decided not to include the assessment criteria of meta-modeling knowledge in their rubrics. Allis perceived meta-modeling knowledge as difficult to assess, as well as not easy for students to digest. Allis said she might briefly discuss meta-modeling after modeling activities, but felt it was not necessary to assess it.

Missing criteria in MOA

From the assessment rubrics, we found that no participants attempted any criteria for assessment of PRAC-plan, PRAC-interpretation, META-modeling, and META-evaluation. Modeling planning (PRAC-plan) in the modeling practice would have significant impact on model construction. In model planning, students brainstorm and suggest a justified plan to create

a model. In normal usage of modeling, the model planning is closely related to what the purpose of model is and how the model represents the target to be modeled effectively. The absence of assessment of model planning implies that in many cases, students had no or little opportunities to plan their own modeling, additionally, the prospective teachers did not notice the importance of model planning and the interconnection between model-planning and other modeling processes. The assessment of students' practice of model interpretation (PRAC-interpretation) can be difficult if students do not explicitly express interpretation of their models. In fact, in the model revision process, students interpret their models and then revise them. In other words, students cannot revise without testing and interpretation of the initial model. However, it is important to note that the participants tended to examine the modeling process through the revised model, as a result of comparing to the initial model and reflecting the difference in quality between initial model and revised model. Oftentimes the model interpretation is an implicit process unless students are asked to express their interpretation. However, model interpretation can be a really important component when students learn scientific concepts through modeling. Even though students do not plan and create their own models in the classrooms, and are given modeling activities by teachers, students still interpret and comment on the models. If a teacher wants to know how students learn a specific concept through modeling, the teacher is able to assess students' model interpretation related to the concept. The absences of criteria of META-modeling and META-evaluation signify characteristics of the prospective teachers' notion about meta-thinking. For example, Allis indicated that meta-thinking exceeds the students' cognitive ability and limited its role within her planned instruction to a short time by dealing with meta-modeling knowledge as a short discussion topic in modeling activities. Obviously, the assessment of meta-modeling knowledge was not favorable for Allis.

The lack of assessment criteria for Meta-modeling and Meta-evaluation arise from similar notions of the students' abilities and capabilities. However, the knowledge of modeling process (Meta-modeling) and the knowledge of how to evaluate models (Meta-evaluation) of students would enhance the quality of models and quality of modeling process to create good models. Explicit instruction on meta-modeling knowledge can be one approach to ensure that prospective teachers gain insight into the importance of meta-modeling knowledge and how to teach meta-modeling knowledge in secondary science teaching. Thus, from these missing criteria of the participants' MOA rubrics, we learned that prospective teachers need support for understanding the whole process of modeling, ways of assessing it, and how to give valuable feedback to the students. In addition, if we can promote prospective teachers' understanding of interconnectedness among MOA criteria, and thus increase their own meta-cognitive thinking regarding MOA, the prospective teachers will be more likely to recognize how to teach science with models and modeling with integrative approaches of MOA even in a modeling activity.

PART II: Cases

In this section, we would like to share the five research participants' cases with additional details as representatives of how prospective teachers approached modeling-oriented assessment (MOA).

Jodice – Modeling for Better Understanding of Concepts

Jodice is one of the MAT students among prospective teachers. At the beginning of semester, he said he was neither familiar with modeling nor aware that the modeling practice was emphasized in NGSS. However, when he was taught about the nature of modeling in the

methods course, he mentioned later that he had been familiar with the practice but not with the term, 'modeling'.

I was familiar with the practice but not with the term. I did not know that it was called modelling. Once I have been taught and explained to what it was, I was aware that I've used it many times (Jodice, Interview, 10/02/2015).

Jodice's familiarity with modeling practice was mostly related to understanding of models as a visualization for science learning.

I'm in life science so I feel like as you get to high school, you get to cells, you get to very small things that are abstract. Without having a model, there's something that kids can't look at and play around with. They'll never really understand what they're dealing with. (Jodice, Interview, 10/02/2015).

However, he continued to explain his growth in understanding of models and modeling.

I would say that initially, I would only ever think of models as visualizing a structure, not as much as an experience. If you told me models, I would say a model of the earth or a model of a cell or a model of a physical thing. Like an Atom. After learning more about the models and how the NGSS talks about them, it's interesting that you can make models of actions, things that occur. It's a different way for me to think about that. (Jodice, Interview, 10/02/2015).

Jodice mentioned how his development of knowledge of models and modeling more broadened greatly in the methods course. He also developed ideas about the instructional uses of modeling while noticing the limitations of models and needs for appropriate models for students. Jodice believed that modeling is a really great tool for

fostering students' conceptual knowledge for science learning. He also recognized that a model is a representation of key features of phenomena with limitations.

Modeling is about giving the students an example or a structure or a phenomenon that they can practice within the limitations of the model. They all have limitations but giving them something that they would not normally be able to experience or see or touch or feel in every controlled way and that they can explore it without having deal with any of the distractions or other information that you would normally get in real life...in Physics in a normally real life you have to deal with friction and then airspeed. When you do models, you could say, 'No, we're only talking about these two aspects and interrelated way for kids to kind of explore it'.... something I've noticed since we are imported modelling is to have an appropriate model. I feel like its very easy to use a too complex or too simple of a model. That's dangerous because if it's too complex of a model to kids, the students will become overwhelmed. You're having to have them focus on a single part of it or something and it gets to be too much or too simple of a model and that doesn't challenge their conceptual knowledge enough. You have to make sure you have a really appropriate model to make sure it does exactly what you wanted to do, not too much and not too little. I think one of the most obvious trick as we just mentioned is that modelling is really good for developing your conceptual knowledge but there are time limitations.... If they can take the time to become engaged and invested in the modelling activity, they will definitely come out with a better conceptual understanding. (Jodice, Interview, 10/02/2015).

Since Jodice's view of the benefits of modeling was focused on the developing understanding of concepts, he also put more weight on conceptual understandings in

assessment using models. He explained, “how the model related to those concepts and helped give them a deeper understanding and may have corrected some misconceptions that the students had after the explore activity.” (Jodice, Reflection, p. 6).

In the assessment rubric, Jodice’s topic was natural selection and animal adaptation. *Figure 3* shows the example of a thematic map of Jodice’s case. He planned to do a modeling activity during which students would build bird beaks as a means for exploring bird adaptation. Jodice wanted students to face their misconceptions through the modeling activity. He broke down the grade in terms of five main criteria: understanding of concepts, model quality, essay quality, modeling practice, and meta-modeling. Jodice planned for the greatest proportion of points (i.e., 40%) to be awarded relative to the understanding of science concepts (adaptation and natural selection). In Jodice’s rubric, the essay is a part of the model where students can describe why the bird beak has a particular look and how the bird beak relates to animal adaptation and natural selection. The bird beaks are three dimensional physical models and Jodice asked students to write detailed descriptions of their models. He believed that students would be able to explain their model, and thus what the models represent, in their essay. Jodice felt that through the process of creating their essays, students would have opportunities to think about the purpose of the model, why the models are developed, and how models can be applied all of which are about meta-modeling knowledge.

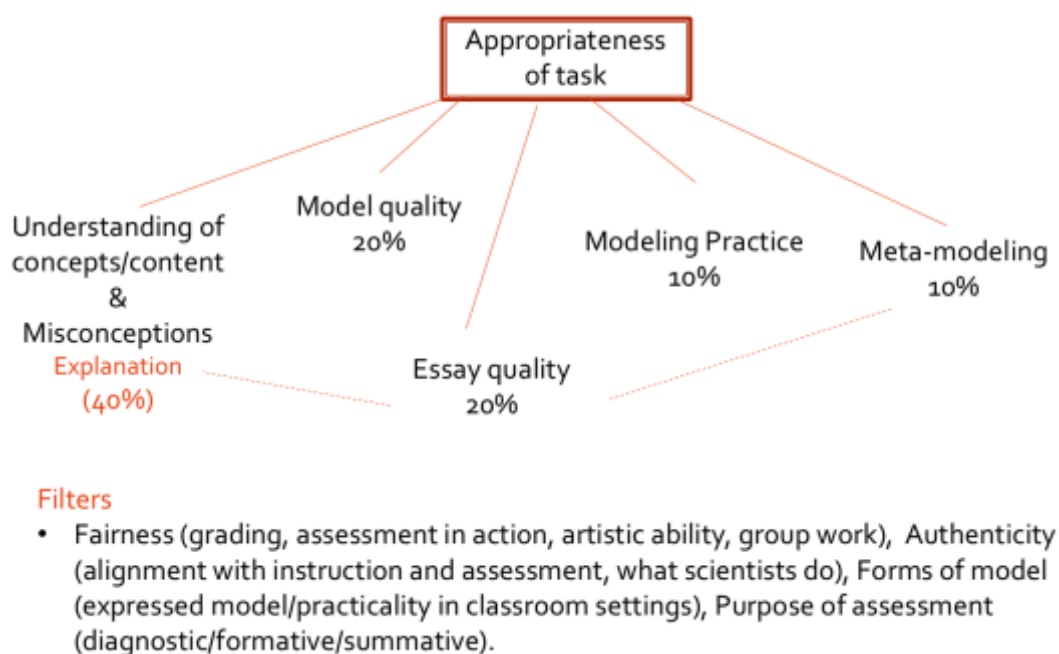
Jodice questioned the subjectivity related to grading in terms of assessing models that students created and the modeling process.

I did this because my goal was that the students created the model effectively and understood why it was made, and how to use it in relation to the concept. The modeling process is important, but I mostly used the aspects of teamwork and using appropriate

materials to represent in my assessment.... so... to grade students on that I think it would be difficult and to assess them on it would be difficult... the goal should be to make it as little as... to make it not be very subjective. That's why I like the written diagrams. (Jodice, interview, 11/9/15).

So, Jodice was not willing to assess modeling practice and allotted only 10% of the total possible points to this within the assessment rubric. The practice of modeling might be important but it is difficult to assess in action in his view.

Figure 4.3 Thematic map for Jodice



In particular, Jodice's concern was that assessment in action can be unfair because he cannot observe the whole period and each group's process at the same time. Jodice thought he might need video-taping for assessing students' modeling process to observe better and to be fair in assessment. With the same reason, he thought the artistic ability in modeling should not be considered in the assessment.

Even if you weren't as good of an artist of somebody else. If it's messy and it's unclear that doesn't have to do with your artistic ability...maybe that student isn't good of drawing maybe that student has artistically inclined and that student is getting points based on...They model artistically correctly enough for you to understand what they're trying to tell you but maybe not judge them based on the quality of their ability to draw or build something (Jodice, interview, 11/9/15).

Figure 4.4 Filters when creating MOA rubric (Jodice) – impact on assessment

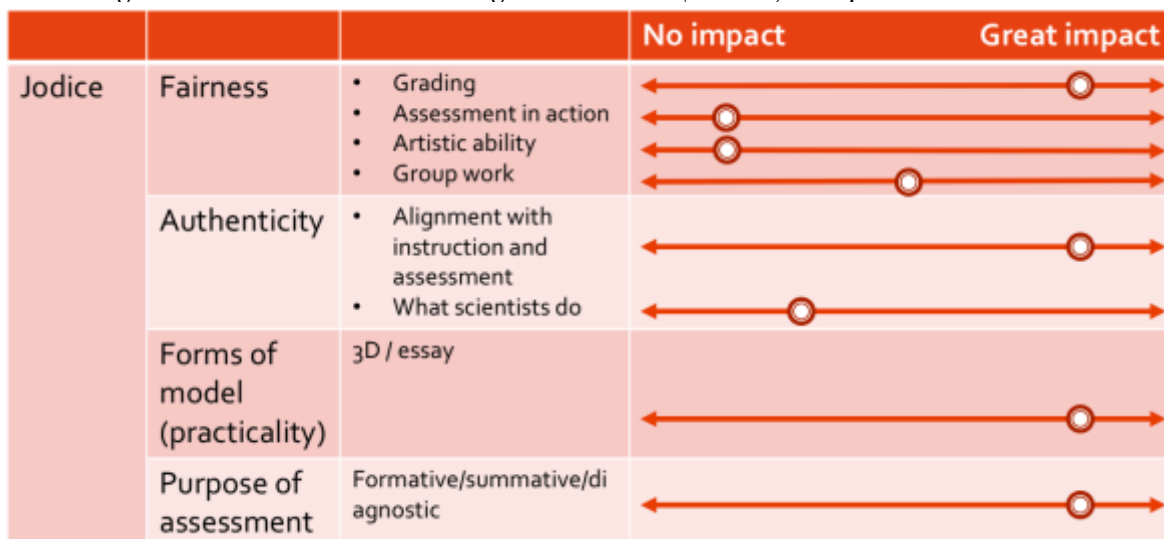


Figure 4.4 shows what filters the Jodice considered in creating a rubric in MOA. 'No impact' means that the consideration was not be reflected in assessment. In other words, it was not an impacting factor (i.e. filter) when creating the MOA rubric. 'Great impact' means that the participant put great consideration on assessment to this factor when creating MOA rubrics. Jodice was sensitive to the assessment context and his greatest concern was fair grading in MOA. Jodice pointed out the fairness issues in resources and grouping, noting that being assigned to a better group was also related to fairness. Jodice's filters implies that MOA as an assessment

should have the practical features as an assessment that can be applied in classroom setting. Also, MOA needs to be contextualized as an assessment.

Physical models are usually not too difficult but sometimes you get into the issues of a lot of these physical models students are kind of ... probably in schools they comes an out of class project and then you have some kids you have more help at home or they're in a better group... And then maybe your assessment ends up having difficulty... 'cause maybe they both finished at the concepts maybe one of them just had...more resources can make a better model. (Jodice, interview, 11/9/15).

For Jodice, authenticity meant the alignment with instruction and assessment rather than the similarity to what scientists do. According to Guilkers et al. (2004), authenticity in authentic assessment is characterized two fold: similarity to knowledge, skills, and attitudes that reflect competency in professional life and the alignment with instruction and assessment. Jodice's ideas about authenticity were more about the alignment with instruction and assessment in his rubric. In contrast, he considered appropriate adjustment and implementation of authenticity as a function of his own professional competency relative to the level of students. For instance, Jodice mentioned the use of appropriate models, believing that they should be not too complex and not too simple as instructional strategies. This may be because Jodice thinks of modeling as an instructional and assessment tool for understanding of concepts including ascertaining the misconceptions of students.

Jodice set his rubric for summative assessment using MOA. So, his concern for grading seems reasonable. Jodice designed the assessment task to build a 3D physical model with written description in the form of essay.

Jodice' Assessment of Meta-modeling knowledge

Jodice included two criteria of Meta-model and Meta-purpose through the form of an essay. Jodice wanted to assess students' knowledge of how to apply the model (Meta-model) and what the model was intended to convey (Meta-purpose) in his rubric. His interpretation of how to apply the model is how the model can be applied to other situations or context, in other words, the generativity of the model. This is important knowledge about a model which has a predictive power in similar situation or context. And, to make and test predictions of scientific events is one of the important roles of scientific models (Gilbert & Boulter, 2000; Harrison & Treagust, 2000). What the model is intended to convey can be explained as knowing the purpose of the model and what the model is representing. Jodice mentioned, for instance, that students need to discuss why their models reflect what happens in nature in their essay. Jodice valued students' analytic thinking on their own models and modeling processes, which is a key idea that comprising meta-modeling knowledge.

So I think the idea of their having to like really analyze their own modeling processes and what is a model and how does a model work and how do you develop models. I think it's really important but I think it's something that you could maybe touch on every time you perform the modeling activity in some way maybe have them do the model or even before I had do the model but make sure they're getting like so how are you developing this model and what concepts are you thinking about. (Jodice, Interview, 11/9/17).

More importantly, Jodice understood the interconnectedness of the three dimensions of MOA. In fact, the interconnections were neither mentioned nor emphasized in the methods course. We found Jodice developed the knowledge of the necessity of assessment of meta-modeling knowledge. He valued the assessment of the students' effective construction of the

model and understood the purpose of the model. Jodice showed that knowledge of a model (META-Model) influences model construct (PROD-construct) such as what model components should be included to explain animal adaptation. He explained his understanding of assessment of meta-modeling knowledge in this way, "...my goal was that the students created the model effectively and understood why it was made, and how to use it in relation to the concept." (Jodice, Reflection, p. 6). Jodice approached assessment of meta-modeling knowledge through essay. For him, the essay was the place that students could explain their physical model and at the same time describe what and how the model represented. This knowledge Jodice's approach to assessment implies that he tried to measure the model components which are included in physical models, as well as students' understanding of the purpose of a model. In other words, when knowing what and why the model is representing, the construction of model components can be influenced by the purpose of the model.

Shannon – Model Revision with Collaboration, and Student Ownership

Shannon also had similar experience with modeling as the other prospective teachers at the beginning of semester. She had limited experience with modeling in her schooling, and was unfamiliar with modeling practice and assessment involving models or modeling. Shannon described her understanding of modeling as, "I think that the things that we've been doing that we've been called modeling in the past for me was called demonstrations or experiments." (Shannon, interview, 10/08/15). Shannon also responded that she never thought that models or modeling could be assessed. Shannon expressed, "I made a cell model when I was in school and models of other cellular systems and things but I never had to think about how they were assessed except for me getting a grade, so before this course." (Shannon, Interview, 11/13/15).

Clarity, completeness, and accuracy. Shannon wanted to assess if students included needed model components and correctly labelled them (PROD-Construct). One of the goals for assessment using models and modeling for her was to assess students' understanding of concepts by modeling. Shannon valued the accuracy of model components that she felt students need to know and wanted these included in their models. In a class group discussion when the prospective teachers were given examples of student-generated models about volcanic eruption, Shannon realized what students' models might look like. Shannon's group in the discussion came up with clarity, completeness, and accuracy as criteria for assessment of the models. These criteria fell into the category of 'Aesthetics and features' of Nelson and Davis (2012)'s study, but Shannon's perspective was more focused on the model's presentation of clear expressions and its ability to communicate with others. Shannon noticed that sometimes in student-generated models it was difficult to recognize what students drew and what they wrote.

I think that if they were asked to include the components of the earth and the plates and if they were given a specific set of things they had to include, then it would have been easier for us to assess what they did write and what they did not include because they all included different parts and some were labelled and some were not but... we did like clarity, completeness, and accuracy I think, like if they had all the parts and then were they right and if they were right, could we actually read it. It was kind of way we were thinking. (Shannon, Interview, 11/13/15).

Model Revision & Collaboration. In Shannon's rubric, she included collaboration as a criterion and felt that students needed to provide constructive feedback to their peers when they were asked to collaborate. She planned to assess how students revised their models with emphasis on

collaboration (PRAC-revision and PRAC-collaboration). This collaboration was designed to improve initial models by reflecting on peer feedback in model revision. In terms of revising models, Shannon recognized that model revision and collaboration in modeling practice are closely related to what scientists do as part of peer-reviews in scientific communities. Thus, she also demonstrated the knowledge of how model revision and collaboration practice are intertwined in scientific knowledge development. In comparison to other participants, Shannon was the only one to clearly stated collaboration as a feedback directly related to model revision. Thus, Shannon's knowledge of the interconnectedness of model revision and collaboration within MOA could promote students' modeling practice in a more integrated way.

Shannon tried to assess how students develop and revise their models through modeling activities related to photosynthesis and cell respiration. Shannon described the purpose of her MOA as evaluation of development and revision of students' models in the process of learning photosynthesis and cell respiration. In her assessment of understanding of concepts through model creation and revision, naturally Shannon focused more on the modeling process. Shannon used 2D drawings as a form of modeling, because she saw the benefits of drawing in assessing students' reflective thought process. Shannon wanted to see how students understood the content knowledge and how to improve their understanding of the knowledge through model revision. She emphasized the importance of model revision for validating students' understanding of the scientific concepts. In her modeling activity, she tried to have students experience the process of photosynthesis and cell respiration through hands-on activity with appropriate representations, so that students could better understand the phenomena.

In addition, Shannon recognized the value of modeling as an instructional strategy and as a formative assessment for student learning.

I think this is a standard to make a model, so I could write about how we...because we did only it was the first day of cell respiration, so we just formatively assessed it like what did they get out of the lesson today and the models were not extremely well-developed, so I would go through and if they put CO₂ or oxygen on the wrong side, I would like circle it and just write “is this an input or an output” and kind of just give them feedback on it, not a grade and they are getting[the assignment] back today I am not there, but she is going to give them back today and they have five more days of cellular respiration, so they are going to work on them.” (Shannon, Interview, 11/13/15).

Implementing modeling activity and her PCK on modeling instruction. Although she expressed her beliefs about the importance of allowing students to actively model phenomena, she sought to implement a structured approach in her model-based instruction. In fact, Shannon had an opportunity to teach photosynthesis and cell respiration and implement a modeling activity on the topic in her practicum classes in a middle school. After the implementation of the modeling activity, she realized that students could not easily connect the physical activity with the drawing. She described the activity with middle school students,

We actually did an activity with them where we had half of the class get in, we were just doing respiration and they did photosynthesis last week and we got them to get in a circle, so we told them you are the mitochondria and then out of paper plates like red, black, and white ones and closed pens, we made glucose, the molecules and then we also had O₂. So we had the students be those and we got them to go in the mitochondria and then the whole class worked together to break them down and make carbon dioxide and water and so they saw how [was] it rearranged and then they went out of the mitochondria and the ATP came out, so we had them do that first and then we asked them

to draw what happened... It kind of work[ed]. It was their first day learning about respiration and they had some like limitations as far as we basically this is glucose, this is what it is, they didn't really know that red is oxygen, white is hydrogen, and black is carbon. So we had to help them a lot, but I think that they took something away from it that it's this stuff going in and coming out basically, because they don't have to know glycolysis, electron transporter of carbon cycle, they will have to know that so. (Shannon, Interview, 11/13/15).

Based on this teaching experience with middle school students, Shannon realized that many students couldn't figure out what the modeling activity meant and some of them just followed other students' drawings. Shannon realized the importance of appropriate feedback for students to learn from each other and improve their understandings by revising their models. She mentioned her development of pedagogical content knowledge (PCK) on how students respond to modeling activities and the challenges for students in modeling.

These are things I don't think that I would have known if I hadn't done this...if I made this rubric without ever having done this in the classroom those things probably would not be on my rubric because I wouldn't think. (Shannon, interview, 11/13/15).

Shannon realized how scaffolding was needed to engage students in the modeling activity. She also recognized that students had difficulty in understanding the analogy between the representations and concepts which can be considered as a mapping skill in meta-modeling knowledge. She actually assessed students' understanding of concepts through questioning based on student-generated models as reflected in the quote below. However, Shannon realized that students couldn't connect modeling activity and representation easily.

What I noticed when they were drawing these models yesterday, was that they did not actually know what the oval from mitochondria represented, so they drew this oval, because that is how they had kept seeing it during the lesson, but when I asked what is this oval, some of them would say, "Oh it is the cell wall," and some of them would say, "Well it is the mitochondria," but they did not connect that the mitochondria were in the cell, so I thought they didn't know why they were making the drawing, which is that meta-modeling. That was our whole concern with that. We were telling them to draw it and they had seen on the board, we put an illustration to help them with the activity of making a circle. We had put a diagram of what the activity was supposed to look like, making an oval in this part of the room, so that we can reference that. So there wasn't chaos in the classroom when we were doing that. Most of them kind of just remembered that and drew that as their model and did not know why. They just drew, basically making a circle in the room and stuff goes in, stuff comes out, but they did not know why. (Shannon, Interview, 11/13/15).

This finding suggests that the authenticity of modeling practice will be diminished if students don't know what they are doing and why they are doing it. Shannon recognized that this form of awareness can be meta-modeling knowledge. She further recognized that a lack of reflective thinking about modeling could hamper students' understanding of concepts and engagement in modeling activities.

Assessment of Meta-modeling knowledge and Student ownership. Shannon planned to assess students' meta-modeling knowledge through a written rationale where students would explain the relevance of their model. She explained the model as a representation of the processes of cell respiration and photosynthesis within cell organelles. She mentioned, "I want students to

recognize that models are intended to be a tool for them to use when explaining concepts to others” (Shannon, Reflection, p. 4). Her view of the purpose of a model was that a model is a tool for explaining concepts and communicating with others. At the same time, Shannon’s pedagogical knowledge of modeling enabled her to plan to assess her students’ understanding of the purpose of models. Shannon included a criterion related to meta-modeling knowledge which is Meta-purpose. She addressed the challenges in assessing meta-modeling knowledge in an interview.

So when I was making that rubric of a meta-model, the meta-modeling part, it was the most difficult for me because we want the model to be a drawing that they can follow visually, but if we don’t get them to somehow write down an explanation of why they drew it that way, we cannot really put it on a rubric, so unless I say, "Can you write down a few sentences about why you chose to do it this way?" I don’t know why they chose to do it that way, so then I cannot understand how they were thinking about their modeling (Shannon, Interview, 11/13/15).

Shannon understood that written description of the modeling process could be a good way of assessing meta-modeling knowledge. She used the written rationale as an assessment tool for meta-modeling knowledge. “Students include a written rationale that explains the relevance of their model. Student describes that the model is representative of the processes that take place within cell organelles.” (Shannon, Rubric, p. 2).

Interestingly, Shannon mentioned when she would assess meta-modeling knowledge. She pointed out that if students have a choice to decide what models are built and how they build them, she would assess their meta-modeling knowledge, but if teachers make these decision, she is not willing to assess meta-modeling knowledge. This can be a significant insight into

Shannon's understanding of assessment of meta-modeling. Shannon expressed her opinion that this meta-modeling knowledge can be connected with students' ownership to a modeling activity, and as a result a lack of meta-modeling knowledge causes problems in both the quality of students' engagement of modeling and the validity of assessment of meta-modeling knowledge of students. Shannon had formed the opinion that when the modeling activity is led by the teacher, students would be less likely to understand why and how to do modeling. She initially described how her modeling activity was a teacher-driven activity. Then after completing the classroom activities, she explained that if students had more ownership, and were given choice and decision-making power related to what they want to model, she would be able to see not only how students got to the model but also how this would become an aspect of their meta-modeling knowledge.

I think sometimes it's useful to see how they got to the model if they are allowed to choose, if they want to build something, if they want to draw something or make something on the computer. If they are given the choice and how the product is, but if I say, make a drawing, they did not have to make that decision, I made it for them, like why did you do a drawing, because you told me to. So I think if they can choose how the product looks like, yes [I will assess meta-modeling], if not, probably not." (Shannon, Interview, 11/13/15).

And she added this,

I definitely think modeling is important in science learning and what I found in my practicum experience is that the students aren't really familiar with modeling. So if I ask them to make an original drawing of something they normally don't know how to start or they don't know how to think about model as a representation of something else. They

want to try the exactly it looks like or they want to copy a picture. They don't really want to create anything on their own (Shannon, Interview, 12/01/15).

From her practicum teaching experience, Shannon began to create a more guided instructional modeling activity due to students' limited mapping skills in modeling. However, at the same time, she also recognized the importance of student ownership in modeling to improve students' modeling practice in relation to meta-modeling knowledge.

Shannon's goal was to have her students better understand the scientific concepts and content about the relationship between cell respiration and photosynthesis through modeling. She recognized that modeling activity needs to be clear so that students are able to connect the physical activity and the learning concepts. Also, Shannon recognized that the modeling process can be an effective formative assessment process through model creation and revision. Thus, it was her goal in assessment of meta-modeling knowledge to guide students to figure out why they were modeling (Meta-purpose) related to what the model represented.

Chris – Authentic Assessment & Coherence

Chris had a laboratory teaching experience as part of his master's degree in microbiology. Even though he had a lab experience, he said he was not familiar with the term 'modeling' at the beginning of semester. But, he had just learned about the NGSS in his summer courses before the methods course and knew that modeling was emphasized in NGSS. Chris remembered his schooling experience with modeling like this,

The one model I remember is my cell model and I knew more, I remember my understanding of the cell increasing just by making that model and I had a horrible time

making that model. I hated doing it but when I was done, I felt like I understood the cell more. (Chris, interview, 12/5/15).

Also, Chris expressed his beginning and his growth,

I didn't know models could be assessed. I always thought it was just like a project you had to do. I didn't know that you could look for misconceptions in models. I didn't know that you could analyze a model. Yeah, models to me have grown in their complexity in this semester, absolutely. (Chris, interview, 12/5/15).

Chris tried to teach students how infectious disease spread in a community and within a population using a **SIR** (Susceptible, Infected, Recovered) computer model and a tag game in his instruction. In his assessment rubric and interview, we found that he began to have a better understanding about the need and importance of modeling based assessment as an authentic assessment. At the same time, he struggled to create a modeling activity in his lesson that was an appropriate instructional and assessment task. Chris realized that designing a modeling activity was more difficult than creating a modeling assessment rubric. He explained, "So, the modeling activity and assessment and rubric, it should be aligned, and it is really get hard..." (Interview, 11/06/15). During the creation of an assessment rubric, he realized that the modeling assessment should be aligned with the modeling instruction, at the same time, the modeling instruction should reflect real-life experience. He also realized that creating the assessment rubric was really a back and forth process. Devising a modeling activity and a matching assessment task were things that he struggled with the most. He could design the rubric based on the nature of models and important components, but creating an appropriate modeling activity aligning with the assessment was not easy for him. His struggling and awareness of the alignment with instruction and assessment, and of the reflection of real-life to modeling activity in the instruction suggested

the possibility of MOA as ‘authentic assessment’ (Guilkers et al. 2004). Chris’ case is similar to Jodice’s case in terms of their concerns for authenticity in assessment. However, Jodice was concerned only about the alignment with instruction and assessment. Chris fully paid attention to both of aspects of authenticity in alignment with instruction and assessment, and similarity to what scientists do, modeling as a scientific practice. This may be because of Chris’ lab experience. While Chris’ case is similar to Jodice, he had more appreciation of MOA as authentic assessment. Thus he struggled more to design an appropriate assessment task for MOA. Finally he decided to use an SIR computer model in ways similar to how scientists would use one.

Variables and terminology. Chris attempted to plan the rubric with the SIR computer model in the way that scientists use simulations, so that students could learn scientific practice through modeling, analyzing the data, and comparing their prediction and the graphs. At the same time, he tried to incorporate physical activity, representing how infectious diseases spread as a tag game. Chris created an assessment criteria in model construction so that future students would be assessed on the use of scientific terminology within their models, and how each variable is involved. In other words, Chris wanted to assess model components needed to be included in the model, and how the variables were accurately labelled in model construction (PROD-construct). “From here, they will match the model to the graph provided to them and determine the parameters and how each variable is involved.” (Chris, Rubric, p. 1).

The proper use of scientific terminology in model-construct is consistent with Nelson & Davis (2011)’s research. Also, in the simulation, Chris wanted students to learn how variables change over time and are related to each other by creating graphs through SIR simulation so that students could ultimately compare their prediction and the graphs.

Coherence of a model (PROD-coherence). Chris created ‘application to real world example’ as a criterion in the modeling product (PROD-) category. Chris knew the importance of a model’s nature of explaining a phenomenon with many variables coherently as a whole, and the generativity with which a model can be applied to other real world examples. He wanted to look at how graphs or explanations demonstrated the connections to a real world example. In other words, Chris tried to assess how student groups’ models held explanatory power and generativity were applied to real world examples. This is a type of sophisticated understanding of models and modeling. In this sense, the coherence of model (META-model) is also interconnected to the model’s predictive nature in real life situation. In comparison to Jodice, Chris’ criteria with respect to coherence was located in assessment of modeling product (PROD-), whereas Jodice’s criteria on generativity was to assess students’ meta-modeling knowledge on the generative nature of models.

Chris never explicitly mentioned the interconnectedness between the coherence of a model and the generative nature of model, nor did he attempt to assess students’ knowledge about the nature of models (Meta-model). However, in our analysis of this approach to MOA, we found implicit evidence of his knowledge that a model has the capability of explaining real work example and being applied to other contexts. Also, he recognized that secondary students’ knowledge of coherence of a model as-a-whole was an important means to explain and predict real life situations. Chris’ case was an exemplar of how the prospective teachers recognized the interconnectedness among their rubric’s MOA dimensions to at least a minor degree. However, in general, their recognitions were not explicit. In addition, even if they recognized the interconnectedness of MOA criteria, the prospective teachers rarely planned to assess students’ meta-modeling knowledge when they assessed model construct, representation or coherence.

Also, Chris expressed his belief that modeling was more difficult than other scientific practices in the NGSS due to a lot of possibilities for representations and interpretations of the same phenomenon.

I would say so, yeah definitely because modeling senses a representation. Of a system or thing. There's a lot of interpretation, a lot of, a lot of... the individual person is going to have a different representation for the same thing so I personally believe yeah it is a lot more difficult to assess a model because they vary from person to person as opposed to like is the answer A B C or D, there's a clear wrong and there's a clear right. So models are definitely harder to assess. (Chris, Interview, 11/16/15)

Chris planned MOA as diagnostic, formative, and summative assessment, and his ideas about grading were more flexible. Chris was also the person who most emphasized the assessment of collaboration in modeling on his rubric. He separated the two different sections in criteria for collaboration: Soft Skill-Group effort and Soft Skill-Individual Contribution to promote individuals' participation and active group interaction by fulfilling their roles and contribution.

Each group will have both individual and group grades. I will do this to balance out as much as possible, as groups work can be very one sided and individual work can also make up for a poor overall group performance. The groups will each have a presentation based off of a specific example and will assign themselves roles within the group (designer, leader, data manager, etc.). The group will receive a grade based off the presentation and look of the project, and each member will receive another grade reflecting their contribution to the work. (Chris, Rubric, p. 2).

Chris showed his awareness of MOA as an authentic assessment in his rubric. His struggles to create the appropriate instructional and assessment tasks were meaningful in seeking a new way of promoting MOA in school settings and the need for curriculum development. His awareness of the model's predictive nature highlights how to teach students modeling as a scientific practice.

Allis – Unwillingness to Assess Meta-Modeling Knowledge

Allis' case is basically very similar to Shannon in terms of the focus of assessment on model creating and revision. She was unique in her plans to have a criterion of aesthetical appearance of models in her rubric.

Allis planned to assess model representation through student actions in the model revision process, explaining "Model becomes more accurate after being revised." (Allis, Rubric, p. 3). In addition to the accuracy of model, she also recognized the relationship between the model revision and the quality of modeling product. Also, she wanted to assess students' representation of human evolution in the final model. "Model efficiently described human evolution by its final product. The model fits with the definition of natural selection." (Allis, Rubric, p. 3-4). Model representation is used to assess how the model represents the content effectively, rather than how students understand the content correctly. However, it is important to note that model representation is closely related to the model content which is represented in a model. In other words, the assessment of content and the model representation have overlap. Model content includes the need for a model to be accurate, so through the model revision process, the model is developing a more powerful explanation. For example, with accurate model content, we can develop different model representations according to student levels.

Unwillingness to assess meta-modeling Allis addressed the necessity of discussion of meta-modeling knowledge, but she didn't want to assess students' knowledge of meta-modeling. She demonstrated her understanding of meta-modeling in the following manner,

This is why I think evaluating the modeling process is necessary, as the instructor can understand that student's learning and thinking process. Students should also understand why they are modeling a phenomena. I think it would be best that if you do not evaluate the meta-modeling knowledge off a rubric, there should be at least a brief discussion after the modeling is over to determine what the activity was about, what the students learned from the model, and what limitations the model may have. (Allis, reflection, p. 7).

However, she decided not to include the assessment of meta-modeling knowledge because she thought meta-modeling knowledge was above students' ability. She explained why she was not willing to include meta-modeling knowledge in assessment, "...that addition may make the rubric quite long and hard to digest for students." (Allis, reflection, p.6).

To Allis, inquiry based teaching was a very important issue in teaching science. She introduced her modeling activity in this way:

Not only does the phylogenetic tree serve as a physical model, but the entire activity is modeling scientific research, as we collect data, research the topic, develop models and ideas, have these models and ideas peer reviewed, and then present these models and ideas to our peers (representing the scientific community) (Allis, Reflection, p. 3-4).

She wanted students to follow what scientists do and experience inquiry-based modeling, so the reasoning behind the process was an important component of her assessment. Allis tried to assess the model product, the phylogenetic tree, as well as the entire process and the final

presentation. However, she decided not to include meta-modeling knowledge for the assessment. She described the reason why she didn't include it:

I thought that the addition may make the rubric quite long and hard to digest for students.

I do, however, believe that meta-modeling knowledge is important, and I would like to use it in an activity that was mostly formative and probably quicker than the activity presented. (Allis, Reflection, p. 6).

Allis' comments implies that assessing meta-modeling knowledge may not be perceived as important enough or be understood appropriately by prospective teachers. Learning scientific process and reasoning behind the process are closely related to meta-modeling knowledge. However, Allis didn't feel the necessity to assess meta-modeling knowledge of future students. Her unwillingness to assess meta-modeling knowledge was mainly because of her understanding and belief of students' level of meta-thinking. However, it is important to know that, oftentimes, when prospective teachers do not understand some part of the task, they think it is above the students' ability – when in fact it is just not something that they understand. Therefore, we need to examine and support the prospective teachers' meta-modeling knowledge directly.

Denise – what scientists do and what students do

Denise was the only participant who was majoring in chemistry. She was also not familiar with modeling and had a limited understanding of modeling at the beginning of semester. Like Chris, she took a summer course, so she was aware that modeling was emphasized in NGSS. But, she described her understanding of modeling in this way;

I've never really thought about it [modeling] too much, because it was never described as this is a practice. It's more of like you'll see it, like they show you this is a model of an

atom, you know, that kind of stuff and you'll see the model they don't think of that specifically as a practice I guess. (Denise, Interview, 10/05/15)

From her comments, we can see that Denise viewed modeling as a demonstration rather than a practice. This finding was consistent with Danusso et al. (2010)'s research. She distinguished between learning science and doing science, and her idea of models was more about watching videos or looking at pictures passively. In her mind, classroom science is dealing with already finished work by scientists and, even in modeling activity, students draw what science says. However, Denise recognized that modeling could involve active learning as students express what they are thinking (e.g. by drawing) in the science learning.

I think because being taught science and actually doing science in a lot of ways are very separate from each other. My idea of models and learning science is more like watching a video of some sort of simulation or looking at a picture and is not as much most of the time actually building something to look at it or drawing what you think on a piece of paper like that's kind of new to me. I was never really told to draw what I think something looks like....it was more, this is what science says this looks like. (Denise, Interview, 12/16/15)

Also, Denise was reminded of her experience in her chemistry labs as a graduate assistant, then thinking of how students in K-12 schools and scientists were different in their approach to doing science.

Actually, using it is kind of new for me. But when actually doing science outside of learning science like being a scientist, I used models more and actually use them [in the labs]. They used models to explain why certain things happened or used a computer model to calculate energies and molecules and use that to explain certain things. I think I

use models more as a scientist and I used them as a science student. (Denise, Interview, 12/16/15)

Her explanation implies that developing and using models is a really authentic scientific practice. As a scientist, she had experienced modeling as a scientific practice. Now she had opportunities to implement modeling to guide students engagement in modeling practice in school science settings as a teacher.

It was good to see it[modeling] implemented because that helps me to understand more of the goal of NGSS to help students become more like scientists because a lot of ways science education is so separate from what being a scientist is. It's like that needs to be bridged and using models and sort of just looking at somebody else's model. First helps the student to be able to build understanding of the model but also helps them to begin to think more like a scientist. (Denise, Interview, 12/16/15).

Denise noticed that there are is a need to bridge between students' own modeling and looking at somebody else's model. In this sense, modeling can be understood an active way of learning as well as authentic science practice (Gilbert, 2004; NRC, 2012). Denise saw the benefits of modeling and she addressed how modeling can enable students to build understandings of models and think like a scientist. In Denise's practicum experience, she implemented modeling with secondary students under her mentor teacher.

In my student teaching I want to because I think if I'm doing that under my mentor teacher, I think that will help me to feel more comfortable trying new things and to see if it works so then a teacher on my own, I have already some idea of what's good to do. With the class since I already know the students because I was already working with the teacher. I learned this semester that they're not familiar with using or looking at models

really. I could see over the couple of days I was teaching them that they became more comfortable with the idea of like doing a modeling activity and so I think it would be good to keep helping them become more comfortable with that. (Denise, Interview, 12/6/15).

From her teaching experience with the modeling activity, Denise noticed how secondary students became more comfortable in learning modeling. This experience might have helped her orientation and willingness to teach modeling to her future students.

Multimodal modeling. In her first interview, Denise expressed her desire to use computer-based models among models in her classroom.

Computer simulation seems to be a pretty useful and interactive. So those are already developed and so it would be good to find some way I can help them to develop models too...it has the ability to do more complex and time saving... It is a computer model where you can build molecules and you can calculate like you set you press the calculate button and it makes the bond links go to like a good distance and the angles of the bonds go to a good distance and you can look at the correct geometry for the molecule or approximate geometry and then you can also calculate where the electron density is on the molecule so it can help you to visualize the polar parts of the molecule and non-polar parts of the molecule. (Denise, Interview, 10/05/15)

After experience with modeling and modeling assessment in the methods course, she created assessment rubrics using MOA. Her topic was 'valance electron and bond model'. Denise designed the modeling activity to consist of two parts. In first part, students were asked to develop representations which account for valence electrons of an atom by drawing a two-dimensional model of an atom. In the next part the representation was a three-dimensional model

which was used to create and describe a bond using two sizes of styrofoam balls and toothpicks. Denise noticed how a 3D model could be useful to represent the bond by connecting the two atoms. Denise designed this assessment to assess high school students' understanding of orbitals and electron pairing as well as electron configurations. Denise put most weight on scientific accuracy of the model in her rubric regardless of the forms of models. Except bonding, the criteria for assessing 2D model and 3D model were basically the same in terms of assessing accuracy of model (e.g., model components and the relationship among the components). The criteria emphasized looking at valence electrons, proper pairing, and orbital arrangement. However, Denise recognized the benefits in the use of multimodal models in representing a phenomenon with multiple perspectives of a model. She mentioned the most diverse forms of models from among all of the participants, and noted that each form had its own benefits for student learning. In assessment rubric, Denise included a 2D drawing, a 3D physical model, and the use of computer models/simulations in the learning process with the purpose of formative assessment. Denise's understanding of the use of multimodal models in instruction and assessment was consistent with the use of multiple indicators to measure student learning outcome in authentic assessment (Guilker et al., 2004; Frey et al., 2012).

The choice of assessment methods allows me to visualize the thoughts the students have developed about valence electrons and show that they can translate among text based, drawn, and physical representations of valence electron arrangement. (Denise, Reflection, p. 4).

Her notion of the ability of translating among different forms of models was consistent with the notion of 'transformative modeling' of Shen & Confrey (2007). The authors explained this transformation among models enhances one's understanding. In transformative modeling,

“the learner coordinates among various kinds of models” (Shen & Confrey, 2007, p.950) and the authors addressed, in the process of transformation and re-construction of models, the learners acquire a higher level of comprehension.

Denise also created a presentation of a 3D model to the class and included collaboration in model development as criteria within her rubric. In terms of the filter she used when designing the assessment rubric, Denise's were the model's appearance and group work. She thought the aesthetical aspect of the model should not be considered when assessing models because her goal for the assessment was to assess understanding of concepts and reasoning through modeling. With this goal in mind, Denise felt some kids might not be very good at or might not have the hand skills for creating models. Also, she thought all group members should contribute to the modeling process but individual contribution also need to be considered.

I like actually building things myself and trying it but some kids might not be very good at that or have the hand skills or they might be lazy and rather just play on the computer. (10/05/15).

When assessing modeling, accurate understanding of previously learned concepts must be considered and what constitutes scientific accuracy must be identified. Appearance may not be as important as the scientific thinking behind the model. The participation of all group members is crucial to this group activity assessment showing the thinking of individuals (Denise, Reflection, p. 4).

Finally, Denise expressed her willingness to use modeling as an assessment tool in an interview.

I think it would be good to use that as an assessment because that helps you to see especially if the student is developing a model, it helps you to see how they understand it and what they're learning. I think I would use it. (Denise, Interview, 12/6/15).

PART III: Cross-Cases Analysis

In this section, we will describe our findings from cross-cases analysis, comparing all of the five participants' understanding of MOA and filters. We will mainly discuss about the filters for assessment and the analysis of interconnectedness among MOA in terms of the participants' understanding.

Filters in MOA

All participants experienced challenges in creating the rubrics that would be used to evaluate students using modeling. They puzzled and questioned how fairly they could give grades when assessing models and modeling. We found many filters were in operation by the prospective teachers when creating rubrics using models such as fairness, authenticity, forms of model, purpose of assessment, etc. A 'filter' is defined as a consideration that influences the decision-making about what is included as criteria or not in the assessment. In other words, a filter is what a (prospective) teacher is concerned when s/he attempts to assess MOA. Thus, a filter could be viewed as an awareness about what we consider in the assessment of models and modeling. For example, we learned from analysis of interview transcripts that Jodice's greatest concerns were fair grading and objectivity of the assessment. Due to the performance-based nature of MOA and classroom assessment practice, grading can be an issue. In Jodice's case, grading was coded as having a great impact (concern) on the continuum. Because of this filter, Jodice hesitated to assess modeling practice in action. He thought he would need a video recording for assessing students' modeling process in terms of fair observation. Likewise, Jodice thought artistic ability should not affect MOA and not consider this aspect when creating MOA rubric. Allis and Shannon planned MOA as a formative assessment and grading was not that big of a concern for them. Allis and Shannon thought they could assess students' modeling process

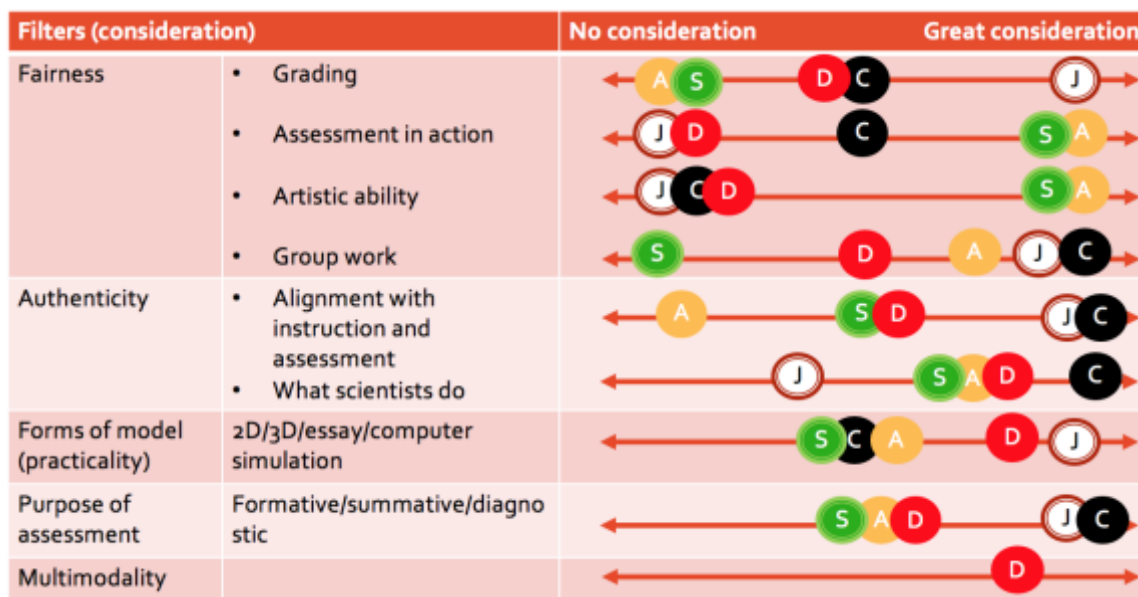
in action, observing their model creation and revision process as they understood the importance of modeling as a learning process. So, for Allis and Shannon, assessment in action in modeling process was an important consideration in designing the MOA rubric. Also, Allis and Shannon considered group work as important in model revision, but put much less emphasis on fairness. Whereas, Denise considered forms of models in relation to multimodality to assess student's understanding of concepts. In this case, only Denise was marked on the continuum of filter, 'forms of models' because of her explicit expression about the use of multimodality in assessment. In both Shannon and Allis' cases, artistic ability such as neatly labeled, readable, aesthetical appearance for communication was a very influential filter. Whereas, in Chris' case, authenticity was the greatest concern when assessing MOA.

Group work was more complicated. Group work was one of the filters for fairness. If a student was assigned in a better group, s/he could get more points. Jodice mentioned group work as a filter for fairness, but because his MOA assessment was basically individual based assessment, group work was not be a big part of the rubric, but the collaboration process was important. So, his position on the spectrum was in the middle. Chris put the most weight on collaboration in his rubric. In Chris' case he devised individual responsibility in his rubric to be fair, but still thought collaboration in the modeling process was important and needed to be assessed. The five participants wanted to assess collaboration (PRAC-collaboration) in the modeling process, but not all of the participants planned to assess students' models (PROD-) as a group assessment (e.g. giving credits for groups). Shannon, Denise, and Jodice planned individual-based assessment for student models even though they were instructed as groups. Allis wanted to assess group models as they were involved in modeling activity as a group. Chris emphasized collaboration and individual accountability within groups, and wanted to balance

assessing both individual and group work based on group presentation and assigned individual roles. Jodice allotted a small portion of the grade to group work in assessing the modeling process, and then set the rubric for assessing models with individual basis.

Attempting to create an understanding of the filters used by prospective teachers in creating a rubric of MOA is significant because knowledge of MOA includes its authenticity, practicality, and complexity of MOA in science classrooms. This knowledge has the potential to promote teachers' use of MOA and inform their use of modeling in alignment with curriculum and assessment. *Figure 5* shows the comparison of filters for MOA among participants.

Figure 4.5 Comparing cases of filters for MOA



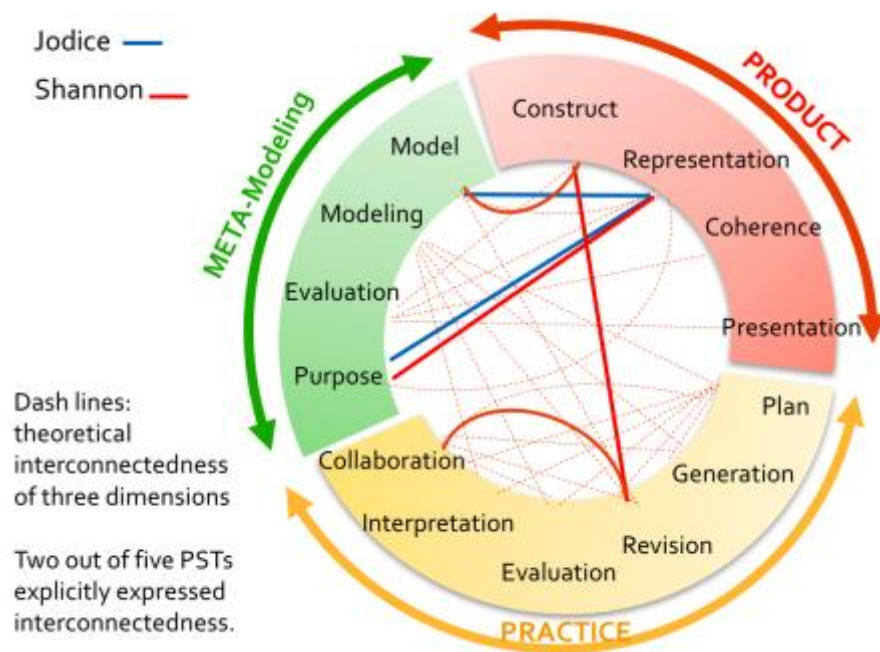
Interconnectedness of MOA components

Figure 4.6 shows the analysis of the prospective teachers understanding of interconnectedness of the three dimensions of MOA. The three dimensions of MOA are theoretically interconnected in nature (Namdar & Shen, 2015). For example, the concepts and how a model represents these concepts (PROD-Representation) is related to the purpose of

model (META-Model). This figure might shed light on whether a student understands what the modeling process is and how the modeling process could create an explanation. Additionally, the model's quality is closely related to collaboration and the model revision process.

In *Figure 4.6*, we can see Jodice and Shannon's understanding of interconnectedness of some criteria among three dimensions as reflected in their assessment rubrics. Only Jodice and Shannon among the five participants planned to assess meta-modeling knowledge in their MOA rubric. *Figure 6* only shows two prospective teachers' knowledge of interconnectedness among MOA dimensions as explicitly expressed in their rubric, reflection or interviews.

Figure 4.6 Interconnectedness of three dimensions of MOA



Commonly Jodice and Shannon developed knowledge of the interconnectedness between model representation (PROD-Representation) in modeling product (PROD-) and the purpose of model (Meta-Purpose) in meta-modeling knowledge (META-). This means that they felt that model quality could be influenced by the students' knowledge about the purpose of the model.

And, both Jodice and Shannon tried to assess meta-modeling knowledge through written description (essay, written rationale). An understanding of the interconnectedness of the three dimensions of MOA is important in guiding a comprehensive and integrative assessment of models/modeling in modeling tasks. Different types of dilemmas may need different supports and in supporting teachers, the interconnections must be acknowledged. Likewise, all criteria among the three dimensions of MOA are interconnected. However, not many prospective teachers could recognize the interrelationship among MOA dimensions. Two out of five PSTs explicitly expressed interconnectedness among criteria of MOA.

Conclusions

From the prospective teachers' unfamiliarity with modeling, it was learned that most of them were not prepared for implementing modeling due to lack of experience in their own formal education. Some prospective teachers also found from their practicum experiences that contemporary secondary students are also not familiar with modeling. With emphasis on modeling practice in the NGSS, teachers' understanding of modeling and preparation for effective implementation of modeling in science classrooms have become important issues. Modeling is definitely an important scientific practice similar to what scientists do, however, oftentimes modeling in science classrooms is quite different from that of scientists'. Many teachers perceive modeling just as a pedagogical practice to teach science. In fact, students need to experience their own modeling practice, and create and revise their own models. And, teachers need to be well equipped to scaffold students' effective modeling activities. Modeling practice in science classrooms needs to be authentic and inquiry-based with opportunities for creating new models to explain and predict scientific phenomena based on new evidences. However, teachers

realize that even implementing a good modeling activity to convey scientific concepts and curricular models (Gilbert, 2004) is still challenging. It is important to note that pedagogical use of modeling to teach science is related to the curriculum teachers need to cover. A model cannot be separated from the model content that a model represents. Manz (2012) addressed the importance of co-development of content knowledge and modeling practice in modeling activities. In this sense, being interested in the assessment of modeling product, modeling process, and meta-modeling knowledge is significant in the implementation of modeling with fidelity as well as learning scientific content.

The prospective teachers developed the knowledge of modeling and modeling-oriented assessment from the beginning of semester. The prospective teachers developed their knowledge of the nature of models/modeling, modeling in science instruction, forms of models/modeling, modeling-oriented assessment (MOA) in relation to science instruction that was part of their previous science learning experiences in formal education. In particular, each prospective teacher mastered different knowledge of MOA. Allis developed knowledge of model revision (PRAC) and changing nature of models (META-model), but was not willing to assess meta-modeling knowledge of future students. Shannon also developed knowledge of model revision. But Shannon recognized the importance of student ownership in modeling and the interconnectedness of MOA dimensions and attempted the assessment of meta-modeling with a written rationale. Allis and Shannon commonly developed modeling as a formative assessment tool for giving feedback to learners in relation to understanding of the modeling process. Jodice struggled with the assessment context and developed knowledge of assessment tasks in MOA in a practical and authentic way. He showed his sophisticated understandings of MOA through creating criteria of meta-modeling knowledge and interconnectedness of MOA dimensions

through essay. However, Jodice was greatly concerned with the fairness in grading when assessing models and modeling. His filters in assessment implies that there are many considerations we need to think in using MOA as an assessment tool in the school science context. Chris demonstrated the knowledge of coherence of a model (model's role in prediction and coherence with real-life phenomena). Finally, Denise thought of modeling as a scientific practice similar to what scientists do, and developed the knowledge of use of multiple representations in assessing students' understanding of a phenomenon.

Through learning experiences on modeling and creating an assessment rubric using modeling, the prospective teachers recognized that modeling can be an effective assessment tool as well as an effective instructional strategy and practice to learn about doing science. Most prospective teachers tried to implement modeling as instructional tools to enhance students' understanding of scientific ideas. Also, as they planned, the prospective teachers recognized that they could assess the development of students' understanding of scientific concepts from examining the model creation and revision process, comparing initial and final models. This finding is consistent with Windschitl et al. (2008)'s recognition that students have opportunities of sense-making talk through model creation and revision.

By introducing the MOA framework in the science methods course, the prospective teachers had opportunities to think about models and modeling thoroughly in the context of modeling curriculum, instruction, and assessment. Most prospective teachers agreed with the importance of understanding the three MOA dimensions: modeling product (model itself), modeling practice, and meta-modeling knowledge. On the other hand, the prospective teachers questioned whether modeling could be practical or authentic in terms of implementations as an instructional and assessment tool in classroom settings. The filters that the prospective teachers

identified when assessing models, modeling, and meta-modeling knowledge were fairness, authenticity, purpose of assessment, and multimodality. Because of the filters, the prospective teachers selectively created criteria in the MOA rubric. The filters signified the prospective teachers' understanding of authenticity and practicality of MOA. The prospective teachers' understanding of modeling as an assessment tool and its authenticity could encourage them to promote modeling instruction in their future science classroom in alignment with assessment and instruction.

However, their development of knowledge of modeling showed limited growth in areas of assessing student learning and modeling skills. Many prospective teachers held the view that meta-modeling knowledge would be beyond the abilities of secondary students, and were not willing to include assessment criteria in assessing secondary students' meta-modeling knowledge. Partially this may be because the prospective teachers' not only possessed limited understanding of meta-modeling knowledge, but also lacked understanding of the importance of explicit teaching of meta-modeling knowledge for secondary students (Schwarz & White, 2005). This finding suggests the need for more support and fidelity in teaching meta-modeling knowledge in science teacher preparation courses with emphasis on authenticity of modeling, similar to what scientists do, regardless of the levels of authenticity with respect to students' abilities.

Although there are benefits of modeling-oriented assessment (MOA) in relation to modeling-based instruction, there are also some limitations and constraints. First, assessment using modeling as authentic assessment in science education requires prospective teachers' understanding of how to maintain subjectivity in the context of classroom assessment. Second, the importance of the modeling-oriented assessment needs to be better understood by evidence

from in-service teachers' experiences in using it in their own K-12 classrooms.

Implications

Teacher knowledge of instructional strategies and assessment tools is important in that it ultimately influences classroom practices (Friedrichsen & Dana, 2005; Grossman, 1990).

Through the design experience of modeling-based instruction and assessment, we found the prospective teachers' knowledge of these processes was enhanced. We believe that modeling-oriented assessment (MOA) is a good fit for authentic assessment in science classrooms. The cases of the prospective teachers imply many important issues in science instruction and assessment. Guliker et al. (2004) addressed the subjectivity of authentic assessment:

“Authenticity is subjective, which makes student perceptions important for authentic assessment to influence learning” (p. 69). This means that teachers need to understand the importance of students' perceptions about what and how they are assessed. In other words, students need to know how they are being assessed and what they should perform in terms of their teachers' instruction with regard to modeling. We also see the importance of prospective teachers' awareness of students' ownership in their lessons and assessment. Jodice and Chris' struggles with filters in MOA implies how well-designed assessment tasks and instruction are important in alignment with assessment. Also, it is meaningful to support prospective teachers' learning of authentic assessment through MOA as a new way of assessment. Chris also became more aware of the importance of fostering students' learning about the nature of a model such as its predictive nature and coherence with real-life situations. In Allis' case, we learned that prospective teachers need to learn the characteristics and the importance of meta-modeling knowledge (Schwarz & White, 2005). This suggests a need for supporting the understanding of

secondary students' ability in meta-thinking when dealing with models and modeling in teacher preparation programs. The prospective teachers' concerns about subjectivity/objectivity and sticking to grading in assessment imply that their understanding of 'assessment' itself needs to be broadened as a learning process. The prospective teachers' ideas about assessment might be based on what and how they were assessed from their schooling experiences or their observations of teachers in practicum school sites. We believe that our educational system is still under the shadow of standardized tests and content-focused assessment items. At the same time, the voices of the prospective teachers on authenticity and practicality of MOA need to be heard carefully in order to foster the use of models and modeling. Shannon demonstrated knowledge of modeling and how to use it in her science teaching and assessment. Even though she did not argue for students' ownership in the modeling activity, she showed her knowledge of how to implement MOA as a formative assessment in a practical way through her rubric.

In this study, we became more aware that there is an urgent need for well-developed assessment plans in alignment with modeling instructions in science curriculum. This need for curriculum development including appropriate assessment rubrics may also be applicable to in-service teachers. We also see the need for the fidelity of a teaching modeling and MOA in teacher preparation courses such as having enough introduction, more examples, and discussions. Finally, there is a need for supporting the development of teacher knowledge of a more integrated way of understanding MOA (interconnectedness).

This study provided insights into the prospective teachers' understandings of authenticity and practicality of the MOA framework in teaching science. The findings of this study inform teachers and teacher educators about the use modeling and MOA, providing a rationale for using it, and shed light on the benefits of thinking about assessment of models/modeling.

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Appendix C. Sample items from the three interviews

Interview question protocol

1. Tell me about your experiences with assessment of modeling prior to your participation in this course.
2. How did experiences using modeling assessment impact your understanding of modeling and assessment?
3. Do you think you have some changes in your understanding of models, modeling process, and assessment of models/modeling as experiencing modeling in this semester?
4. Tell me about the prominent features of assessment of models/modeling that stands out for you.
5. Describe what kinds of assessment of modeling can be used in the classrooms (e.i. diagnostic, formative, summative assessment).
6. Describe how different forms of models (e.g. diagrams, physical models, gestures, etc.) can be used for modeling assessment.
7. Tell me about what you think the possible criteria of assessment in modeling.
8. What sort of challenges did you encounter while engaging in modeling assessment experiences?
9. What do you think are the affordances and constraints of modeling assessment in classrooms?
10. Will you consider using modeling assessment in your future classrooms? Why?
11. In your practicum, if you used models/modeling in your lessons, describe how your modeling lessons were structured. Whether you used models/modeling in your practicum lessons or not, explain the reason for your answer.

CHAPTER 5

THE DEVELOPMENT OF PROSPECTIVE SCIENCE TEACHERS' KNOWLEDGE OF MODELING AND MODELING-ORIENTED ASSESSMENT DURING TEACHER EDUCATION

Research on prospective teachers' understanding of modeling has been focused on their knowledge of the nature of models/modeling or of plans for using modeling in lessons. However, there have been few studies that examine how prospective teachers understand models/modeling in light of how they learn science knowledge during modeling practice and also how assessment of student learning outcomes can occur during modeling practice. It is important to note that modeling practice is emphasized in science curriculum; as such teachers need to understand how to incorporate modeling in their instruction in alignment with its assessment in science lessons.

Overview of findings

The overall research question of this dissertation was '*how do prospective teachers develop the knowledge of models/modeling and its assessment in a science method course?*' Prospective teachers' knowledge development of instruction and assessment of models/modeling were addressed in this dissertation.

In chapter 2, the research questions were: 1) *What are prospective teachers' understandings of models/modeling?* 2) *What are prospective teachers' challenges and successes in learning models/modeling?* and 3) *What is the relationship with MOA and authentic*

assessment in K-12 science education? In the review of literature in chapter 2, the synthesis put forward the idea that MOA is a form of authentic assessment in science education. This review also found evidence of how prospective teachers' struggle with understanding models/modeling. In particular, prospective teachers tended to struggle with how to incorporate modeling in their science instruction in relation to model evaluation, revision, and meta-modeling knowledge (Schwarz, 2009). We examined how the two different constructs, MOA and authentic assessment are related to each other, and found MOA to be well matched to the essential characteristics of authentic assessment: 1) reflection of real-professional life similar to the work that scientists do, 2) alignment with assessment and instruction, and 3) assessment of process as well as product. If prospective teachers understand modeling as a real student-centered, active learning approach, and a knowledge building tool for students, they can incorporate modeling in their instruction, along with assessment for feedback of student learning. We addressed the needs to support prospective teachers' understanding of the assessment of modeling: 1) prospective teachers need to understand MOA as authentic assessment in science classrooms, and 2) prospective teachers need to have a comprehensive view of the criteria for evaluating models – product, practices and meta-modeling knowledge, and 3) how to create a multi-component rubric that evaluates student-generated models in alignment with instructional objectives.

In Chapter 3, the research questions were: *1) What instructional knowledge do prospective secondary science teachers develop while designing and implementing modeling instruction during their methods and practicum coursework?; and 2) What characteristics of pedagogical content knowledge on modeling (PCKm) as an instructional strategy do prospective secondary science teachers demonstrate?* To answer these questions, we investigated prospective teachers' implementation of modeling through mini-lessons. We found that the

prospective teachers were not familiar with modeling at the beginning of semester and had little experience with modeling in their own schooling. During the semester, we found that each participant developed different knowledge of modeling as an instructional tool to be used in science instruction. For instance, knowledge of modeling as an instructional strategy was developed when participants created and used a game as a modeling strategy to teach scientific concepts. We also found that the prospective teachers developed knowledge around two PCK components, i.e., knowledge of instructional strategy (KISm) and knowledge of student understanding (KSUm) in their modeling lessons. In addition, the participants demonstrated an understanding of the strong interconnections between the knowledge of instructional strategy (KISm) and knowledge of student understanding (KSUm), which is consistent with Park & Chen (2012)'s study.

In Chapter 4, the research questions were: *1) How do prospective secondary teachers (PSTs) develop understandings of MOA (Modeling-Oriented Assessment) as evidenced by the design of assessment rubrics?; and 2) What successes and challenges do PSTs experience when engaging in the design of assessment rubrics using MOA?* In this study, we found the prospective teachers planned MOA mostly focused on assessing scientific concepts through modeling rather than evaluating models themselves, modeling processes or meta-modeling knowledge. The rubrics created by the prospective teachers were usually missing criteria related to assessment of modeling practices and meta-modeling knowledge. Also, only two among five prospective teachers planned to assess meta-modeling knowledge of students. However, each prospective teacher contributed a different form of knowledge of MOA (than was originally proposed by Namdar and Shen (2015), for instance) such as knowledge of model revision (Allis), knowledge of coherence of model (Chris), or knowledge of use of multiple forms of models

(Denise). In addition, two prospective teachers recognized the interconnectedness of MOA dimensions in the process of creating MOA rubrics. If the prospective teachers understand the interconnections of MOA fully, they can implement MOA in a more integrated fashion. For example, if one's meta-modeling knowledge guides the modeling process (Schwarz and White, 2005), then the modeling process could influence the model quality (product). To answer research question 2, we found the prospective teachers were not prepared to assess meta-modeling knowledge. This is partly because prospective teachers perceive that meta-modeling knowledge exceeds the students' ability to understand, and also partly because prospective teachers lack understanding of what meta-modeling knowledge is. In addition, the data analysis identified filters that influenced the prospective teachers' decision-making about what would be included or not as criteria for the assessment of their future students' models. A 'filter' is defined as a consideration employed by a (prospective) teacher to identify concerns when s/he attempts to assess MOA. It is important to listen to prospective teachers' notions on their filters because the filters are related to their willingness to assess models and modeling, and at the same time, to their preparedness related to the levels and forms of MOA they implement in their classrooms. An example of these filters would be how the identification of "fairness" in the grading of a model should be represented in the rubric created for assessing future student work. This becomes a major issue in the science classrooms when students create models as a group activity as compared to as an individual activity. The prospective teachers' recognition of these issues that form the filters is an important step for their development as teachers.

What does this mean as a whole study?

Ultimately, the issue of the filters is powerfully related to the authenticity and practicality of MOA in science classrooms. The prospective teachers' understanding of filters such as fairness in grading, the importance of the forms of models (2D, 3D, drawings, or physical models), purposes of assessment (diagnostic, formative, or summative), etc. are all important aspects of learning to teach. The consideration of these filters is closely connected to 'MOA as authentic assessment', and the degree to which MOA is feasible in classroom settings or not as authentic assessment. In the prospective teachers' minds, assessment during the modeling process is difficult because of an inability to see how fair grading can be accomplished, the difficulty to observe the whole class at any given time, and the challenge of evaluating the work of whole groups even though collaborative research is an authentic scientific practice. The combination of these factors means that, for the prospective science teachers, comprehensive assessment of modeling would not be happening. And as a result, valuable feedback regarding the modeling process for students will not be provided. There is clearly a need for prospective teachers' comprehensive view of assessment of models/modeling (product, practices, and meta-modeling), as well as better understanding of assessment in general. For example, prospective teachers need to understand that assessment can be administrated for different purposes such as formative, summative, and diagnostic assessment. Additionally, it is important for them to understand how the purpose of assessment is to give feedback for students' ongoing learning.

Implications

Implications for science teacher preparation

This study has identified four major implications for science teacher preparation related to teacher education instruction in the use of and assessment by models.

- Importance of experiences with modeling and opportunities for implementation of modeling in teacher education.
- Benefits of introducing MOA into prospective teacher preparation courses in respect to a comprehensive view of modeling.
- Need for support for an instructional emphasis on **knowledge of modeling** (meta-modeling knowledge).
- Need support for development of knowledge of **interconnectedness** of MOA components.

There are a number of additional implications for science teacher preparation that also arise from this study. This dissertation showed prospective teachers need to experience modeling practices by themselves and figure out how they develop, use and assess models, modeling practices, and meta-modeling knowledge in their future classrooms during their teacher preparation program. By introducing MOA and authentic assessment into prospective teacher preparation courses, the knowledge of models and modeling can be enhanced with a comprehensive view of modeling in relation to instructional strategies and assessment tools. In addition, there are needs to support prospective teachers' learning about meta-modeling knowledge (e.g., the nature of models and modeling) and interconnectedness of MOA components in teacher education.

Implications for methodological and theoretical implications

The research methodology and the theoretical framework of this study exposed two major implications for the preparation of science teachers in the use of and assessment by models.

- In the sequence of prospective teachers' learning experience, learning about assessment in general needs to go before introducing MOA in the methods course.
- Further data collection of the prospective teachers' implementations of their lesson plans and assessment rubrics needs to happen in the following student teaching semester.

There are some limitations of this dissertation with regard to design and methodological and theoretical improvements that could strengthen the study. As indicated, if prospective teachers learn about assessment in general before introducing MOA in the methods course, the result of study would be different. For example, if prospective teachers learn about assessment as a learning process and diverse purpose of assessment (diagnostic, formative, and summative) with practical examples, their ideas about MOA criteria would be different. In addition, further data collection of the prospective teachers' implementations of their lesson plans and assessment rubrics in the following student teaching semester with secondary students would strengthen the results of the study. For example, this additional data collection could strengthen better understanding of the participants' knowledge development of models and modeling and how their enactment might change over time.

Directions for future study

Exploration of future research has identified four major directions for science education related to teacher education instruction and assessment using modeling.

- Exploration of ‘filters’ in assessing models and modeling from the views of both prospective and in-service teachers.
- Authenticity of MOA needs to be studied in classroom setting.
- Examination of in-service teachers’ development of PCK in modeling.
- PSTs’ understanding of modeling process, focused on model planning.

Future research on filters in assessing models/modeling are needed from the point of view of both prospective and participating teachers. There is a need for additional research on how each filter functions in relation to identified domains of classroom assessment practices. Also, theoretical ‘authenticity’ of MOA needs to be studied in classroom setting. The primary participants of this study demonstrated many different filters in relation to authenticity and practicality to implement MOA in classroom settings. In addition, an examination of in-service teachers’ development of PCK in modeling is needed. Like prospective teachers started to recognize and develop the PCKm and interconnectedness of its components, it is valuable to examine if practicing teachers also develop PCKm in classroom settings. The research findings informed that there were missing criteria of prospective teachers in their rubric (e.g., PRAC-plan, PRAC-interpretation, META-evaluation). The further research on both prospective and practicing teachers’ understanding of specific criterion among MOA can be conducted. For example, prospective teachers’ understanding of assessment of modeling process, focused on model planning would help provide understanding of this important part of the modeling process.

Conclusion

This dissertation addresses the problems that prospective teachers' limited experiences and understanding of models and modeling have when learning to teach. Its findings are generally in agreement with other existing studies indicated in teacher education. On the other hand, we also make and support claims that the prospective teachers can develop knowledge of models and modeling in relation to instructional strategies and assessment tools. The finding that prospective teachers were unwilling to assess meta-modeling knowledge sheds light on how well prospective teachers' notions of assessment of modeling are formed. This finding is also support for the result of Crawford & Cullin (2004)'s study that prospective teachers are not willing to teach about models and modeling in instruction. Clearly there is a need to support prospective teachers' learning about meta-modeling knowledge. By introducing the categories of possible criteria of MOA in teacher preparation courses, the prospective teachers could have a more comprehensive view of model/modeling-based instruction in alignment with assessment.

The overarching purpose of a dissertation is to add to the body of knowledge in a field. This dissertation study adds the body of knowledge on assessment of modeling as authentic assessment in relation to the established MOA framework (Namdar & Shen, 2015). Second, this dissertation highlights prospective teachers' development of PCK in modeling, supporting Park & Chen (2012)'s study and its connections between the co-development of KIS and KSU among the components of PCK. In particular, this study adds insight into how prospective teachers are able to develop PCK components. Third, this dissertation emphasizes the learning effects of the introduction of MOA in a teacher preparation course in broadening prospective teachers' and teacher educators' understanding of modeling instruction and assessment more comprehensively. In addition, this dissertation showed prospective teachers' views of authenticity of assessment of

modeling. The discussion of ‘filters’ from the prospective teachers implies what we need to consider when we assess models and modeling. This notion of filters also adds new insights to the body of knowledge on modeling-based instruction and assessment as a methodology for its’ practical use as an assessment tool in classroom settings.

Prospective teachers’ understanding of models/modeling, ultimately, needs to be elaborated into a comprehensive view that includes science learning assessment within their classroom uses of models/modeling. The assessment of models/modeling is closely connected to and should be aligned with the learning goals in models/modeling in science curriculum. Modeling is authentic scientific practice (Gilbert, 2004); MOA has essential characteristics of authentic assessment. This knowledge of MOA as authentic assessment needs to be expounded in a meaningful way in teacher education when prospective teachers are learning about models/modeling. It is my hope that this dissertation contributes to a better understanding of assessment of modeling in the context of teacher education.