Chapter 10
Teachers' Views About Models and Modeling Competence Towards Developing Scientific Literacy in Young People

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10.1 Introduction

A scientifically literate public is crucial as our modern world is on the brink of environmental crisis; and solutions for global problems reside in scientific knowledge, evidence, and creativity in solving problems. The concept of scientific literacy is not clearly defined by all, and the concept has shifted over time (Deboer, 2000). Science is a way of thinking used to develop explanations of natural phenomena using evidence and logic (Crawford, 2014). Scientific literacy includes application of scientific knowledge to the situations individuals will encounter as citizens (Bybee, 2015). The current emphasis on scientific literacy connects with a citizen's view of contemporary and sometimes controversial scientific research. For our purposes, scientific literacy is the understanding of scientific concepts, in addition to understanding how scientists think and construct knowledge, including how scientists create and use models; in short, learning about inquiry/practices and nature of science (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996, 2012). Scientific inquiry consists of the methods and systematic ways of investigating phenomena (Crawford, 2000). Nature of science relates to values and underlying assumptions intrinsic to scientific knowledge, including the human aspects of scientific work (Schwartz, Lederman, & Crawford (2004). Reforms for teaching science emphasize developing learners' epistemological views of science (NRC, 1996, 2012). One of the most important products of science is that of models. Thus, teaching about aspects of scientific models and modeling, is of high importance in classrooms, in developing scientific literacy in young people. This chapter focuses on teachers' views about models and modeling competence in the classroom, as teachers engage students in learning how

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to think and reason through inquiry and modeling, and, in turn, foster scientific literacy.

Scientific models are vital in understanding our natural world. The development and use of models by scientists leads to trustworthy scientific knowledge. Citizens encounter models in everyday life. For example, meteorologists create models of weather patterns and of storms and the possible paths of a particular hurricane over water and over land. Citizens see weather forecasters depicting changing models of weather patterns; yet many people, including youth, may not fully understand the changeable nature of scientific models; and, thus, discount the trustworthiness of the models. Many citizens attribute the changeability of models to a lack of knowledge or true understanding. Therefore, in the minds of many citizens they may mistrust science. Understanding how scientists build and use models is at the heart of what teachers need to know in order to develop in their students an understanding of how scientists use logic and evidence.

Models are powerful tools that enable scientists to generate predictions, as well as guide explanation, interpretation, understanding, and discovery (Jungck & Calley, 1985). An important element of models and modeling is that of abstraction (Chap. 17). By simplifying the complex phenomenon (abstraction), that then can be tested, building a model leads to a better understanding of the phenomenon being studied (target) to better understand the target. In this way, models are used by scientists to reconstruct the idea of a phenomenon, to better study it and generate new knowledge. As such, models are refined over time, based on new evidence or new ways of looking at the same evidence. One important aspect of modeling, is to start with what justifies conceiving of something as a model, which relates to an epistemic pattern of model-being (Mahr, 2011).

A vision of teaching science in the twenty-first century is one of teachers supporting students in understanding the nature of science, and engaging in inquiry/practices, including building and using models (i.e. NRC, 2012). While science educators are unified in this goal, promoting scientific literacy in citizens around the world has been a challenge for more than a century (Dewey, 1916). During the early years of the twentieth century, United States education focused on the basis of relevance to contemporary life and contribution to a shared understanding of the physical world by all members of society (Dewey, 1916). Although it is evident children benefit from model-based instruction, the reality is many teachers view scientific models in a limited and narrow sense (Crawford & Cullin, 2004). Practicing and prospective science teachers may view models mainly as pedagogical tools, and they often fail to attribute to models the function of idea testing or idea generating (Crawford & Cullin, 2004, Crawford & Cullin, 2005; De Jong & van Driel, 2001; Justi & Gilbert, 2003). In addition to not fully realizing the power of modeling, teachers may meet resistance from stakeholders when teaching about modeling through inquiry-based approaches and extended projects. Resistance can come from administrators, as well as their teaching colleagues, who prioritize memorization of science vocabulary; over learning about models and modeling, and development of deep understandings of science modeling (Flanagan & Crawford, 2018). Further a teacher's personal beliefs about inquiry and understandings of modeling are important (Justi & Gilbert, 2003) and can present personal barriers to teachers engaging students in modeling.

In this chapter we address teachers' views of competence related to models and modeling and nature of science (model-based science teaching). The use of model-based science teaching connects tightly to developing scientific literacy in young people (NRC, 2012). We draw upon the empirical literature and data from our work with prospective and practicing teachers. There are few published studies specifically on prospective teachers' understandings of models and views of using scientific models in classrooms (e.g. Crawford & Cullin, 2004; van Driel & Verloop, 1999). This chapter will suggest implications related to teachers' modeling competence for the future of teacher education and various kinds of teacher professional development in countries around the world (see Crawford et al., 2014).

10.2 Theoretical Background

10.2.1 Models and Modeling in Teaching Science

We align our view of models and modeling with that of Gouvea and Passmore (2017), "Models are not simply knowledge representations of the world they are epistemic tools for making sense of the world (p. 56)". Viewing models as epistemic tools, one of the important aspects of modeling in science classrooms is that of engaging students in sense making. Mahr (2011) identifies this distinction of that between models of and models for, which is assigned to models as media and models as research tools by Upmeier zu Belzen and Krüger (2010). Further, we view engaging students in modeling as a dynamic endeavor versus a static one. Static models are similar to models as medium as they are representations of a phenomenon. Dynamic models are similar to models as a method, as they represent models for understanding a particular phenomenon. A classic example of using a static model in a biology classroom involves clay or ceramic 3-D representations of the stages of cellular mitosis and meiosis. Models purchased from scientific education companies can illustrate the different phases of mitosis and meiosis. In the classroom, teachers might display these models, and students may make drawings of the different stages in their notebooks, label the parts, and memorize what scientists have already figured out. A dynamic model of mitosis may involve an animation of a human skin cell undergoing mitosis over time, depicting the various time intervals of each stage of mitosis.

10.2.2 Nature of Science

We suggest an understanding of the nature of scientific models is tightly connected with an understanding of what science is, and what science is not, and that science is a way of knowing (Lederman, 1992). We refer the reader to Chap. 4 on the nature of science in connection with models and modeling. We agree modeling competence necessitates an understanding of the nature of science and the practices of scientific inquiry (Schwartz et al., 2004). And the other way around becoming model competent involves learning the nature of science. The recent United States framework (NRC, 2012) for science education promotes teaching about aspects of the nature of science. "Epistemic knowledge is knowledge of the constructs and values that are intrinsic to science. Students need to understand what is meant, for example, by an observation, a hypothesis, an inference, a model, a theory, or a claim and be able to distinguish among them" (NRC, 2012, p 79). Aspects of the nature of science important to teach students include, science investigations use a variety of methods, scientific knowledge is based on empirical evidence, scientific knowledge is open to revision in light of new evidence, scientific models, laws, mechanisms, and theories explain natural phenomena, science is a way of knowing, scientific knowledge assumes an order and consistency in natural systems, science is a human endeavor, science addresses questions about the natural and material world.

10.2.3 Socio-cultural Perspective of Learning

From a constructivist perspective, a learner comes into a new situation already with one's own ideas (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Experiences shape a learner's own ideas. Newly acquired knowledge is built upon previous knowledge. A socio-cultural perspective of learning is one that takes into account both the social and the cultural environment; and what an individual learns is culturally and socially dependent. Knowledge is developed in the context of personal experiences in association with others (Vygotsky, 1978). Taber (2013) writes about students, "what students know, think, and learn are not phenomena at all (they are not directly observed features of the world); they are conjectured theoretical entities that form parts of our explanatory schemes (p. 327)". We view teacher's learning and competences from a socio-cultural perspective, much as we view young people learning from their experiences in context, and influenced by culture and others in a society.

10.2.4 Description of Levels of Competence Development by Integration of Epistemological Views

Facilitating children in classrooms in learning how to think in ways similar to that of a scientist involves constructing mental models, as they develop understandings of complex phenomena. In contemporary science teaching a primary goal is facilitating children in developing a way of thinking. A goal of school science is not just about acquisition of concrete science concepts and principles, but in developing in children the kinds of thinking aligned with that of scientists, as they create and test and modify or discard models. Oftentimes, teachers may believe the best way to help students to learn about the world, is by efficiently transferring to their students the teacher's own knowledge of scientific facts using a direct teaching approach. However, in bypassing the opportunity for children to struggle with making sense of data and creating models, children cannot fully understand models as epistemic tools. It is important to involve children in the hard and messy work of grappling with data and using empirical data to build and test and critique models (Grünkorn, Upmeier zu Belzen, & Krüger, 2014; Upmeier zu Belzen & Krüger, 2010).

10.2.5 Teachers' Modeling Competence and Teaching

In this chapter we take a problematizing stance related to learning and teaching. What students and teachers know and think and the reasons for their decisions can only be inferred, rather than known absolutely. One cannot directly observe what a person learns about science, nor what a teacher believes about science and science teaching. Similarly, we cannot fully understand a teacher's knowledge base or his or her beliefs and intentions to teach science in reform-based ways (see NRC, 2012). We can only conjecture, based on observations; but, we can never really know for sure. This relates to the notion of competence which is defined as a latent construct getting manifest while performing, e.g. during solving a task (Chap. 1).

Our research aims to answer the following questions:

1. What is the extent of teachers' competence in teaching models and modeling, with a focus on models as epistemic tools?
2. How can we assess teachers' competence in using models and modeling in teaching science and developing scientific literacy in their young students?

10.2.6 Teachers' Views About Scientific Models and Modeling in School Classrooms

It is necessary for teachers to hold conceptions of models and modeling at a deeper level than their own students, if they are to be successful in engaging their students in the scientific practice of building and using models. Further, teachers need to understand models and modeling related to the epistemology of science. In reality, teachers may not have had the necessary experiences during their lifetimes that support deep conceptions of scientific modeling. First, previous research suggests teachers themselves may likely have limited experiences in the process of scientific modeling during their traditional teacher preparation programs (Crawford & Cullin, 2004, 2005; van Driel & Verloop, 1999). Second, teachers may not appreciate the purpose of models, or the power of cognitive activities associated with building and using models (Crawford & Cullin, 2004, 2005). Third, it is not evident that many teachers value prioritizing classroom time on engaging students in modeling and in understanding the nature of scientific modeling, versus learning definitions of scientific terms and memorizing key facts related to disciplinary core ideas. Previous studies have addressed these limitations (Crawford, 2007). Combining teachers' knowledge of models and modeling with an understanding of the nature of science, creates an important shift towards an epistemic focus on teachers' competence of using models and modeling.

Creating educational and professional development opportunities for prospective and practicing teachers can be of great benefit (Schwarz, 2009). It is important for teachers to have opportunity to reflect on and apply a framework, and to address potential roadblocks in teaching about models and modeling. The notion of a teacher's intentions to teach in a certain way, is as important as a teacher's competence, in this case, of models and modeling, and in teaching about models.

10.3 Design and Methodology

10.3.1 Study of Prospective Teachers' Views of Modeling Competence

In the following we present data from a recent study of a group of prospective secondary science teachers in the United States. These new teachers represent the future of science teaching, as they had opportunities to engage in learning about the most recent frameworks for teaching science (NRC, 2012). The study took place in a large university in the southeastern part of the United States. The university has a known reputation for admitting highly qualified students. The students in this teacher education program earn the equivalent of a major in a science discipline (chemistry, biology, physics, or earth science). The teacher education program typically spans two semesters of the final year of a university student's science teacher certification degree program. The teacher preparation program is similar to many other research-intensive university teacher education programs in the United States, in that there are two to three semesters of work related to pedagogy, including the practicum work.

10.3.2 Context of the Study

During their first semester of the teacher education program prospective science teachers completed three science teacher education courses (a technology course, a science teaching methods course, and a practicum in a local school). During the second semester, prospective science teachers engaged in a full-time student teaching internship in a local school and they participated in a 3-hour evening course that met once a week at the university. This course was titled: Reflections on Teaching Science. The course focused on critical reflection by each prospective teacher of his/her classroom teaching through written and oral analyses of both pedagogy and student learning. The course emphasized teaching science as inquiry, with a focus on scientific inquiry/practices, including that of building and using models and modeling. During the course the prospective teachers submitted weekly reflections on two different incidents that happened in their teaching that week. One incident they identified as a challenge; and the other, as a celebration. Prospective teachers read selected published articles about inquiry teaching and learning and scientific practices, including specifically the practice of building and using models (i.e. Falk & Brodsky, 2013). Articles included those published in both research and practitioner journals. Prospective teachers wrote commentary on how their own teaching connected, or did not connect, with pedagogy described in these articles. Class discussions gave opportunity for prospective teachers to publicly exchange ideas with their peers and the instructor. Further, the prospective teachers wrote two versions of a philosophy of teaching and learning statement; first as a draft early in the semester, and later, as a revised statement at the end of the program, incorporating real examples from their own teaching.

10.3.3 Participants and Data

The research participants (n = 35) included secondary science prospective teachers, from two consecutive years in the program (2016 and 2017). In the middle of the second semester of the program, participants completed open-ended surveys to demonstrate their understandings of models and modeling. The survey included questions such as, "What are scientific models and what do they do?" Participants were asked to provide examples from their own teaching experiences in support of their statements. The survey did not directly ask about each of the five aspects within the framework for modeling competence (FMC; Chap. 1) used for analysis. The survey was intended to allow for open response by participants.

10.3.4 Data Analyses

We analyzed the written responses using the FMC to determine teacher understandings of both aspects of models and complexity of understanding (Fig. 1.3). As described in Chap. 1, the FMC categorizes models and modeling into five aspects *Nature of Models, Multiple Models, Purpose of Models, Testing Models, Modifying Models* (Chap. 1). Within each of these categories there are three levels of modeling competence ranging from limited (level I) to more sophisticated understandings (level III). First, written responses, including examples from teaching, were deductively coded for the five aspects of models. Then the responses were coded for level of complexity ranging from I to III as defined by the theoretical framework. Finally, responses were inductively coded to find any emerging understandings that were not applicable to the framework.

10.4 Findings

The written surveys yielded 108 responses from the 35 total participants. *Nature of Models* coded for 40 of the responses, and *Purpose of Models* coded for 24. At least one of the two aspects (*Nature of Models and Purpose of Models*), were mentioned by nearly all 35 prospective teachers and were mentioned together by 16 of those. Many participants believed models to be a representation, or a visual copy of a natural phenomenon; and, the purpose of models was mainly to teach students about science concepts (Fig. 10.1). One participant acknowledged the use of models for prediction (level III), and two wrote about the integration of related variables (level II). However, while the majority recognized the nature and purpose of models, the prospective teachers' perceptions of modeling were generally limited to a level I understanding in both of these aspects.

The remaining three aspects of models were mentioned rarely. *Changing Models* was coded for four responses, all at level II complexity. Prospective teachers seemed to skip the level I concept of correcting errors in the model, to revising the model based on new findings. These prospective teachers detailed this process in their examples. Some prospective teachers would ask students to construct models of phenomena they were studying, and then ask students to revisit and revise their models throughout instruction, using new knowledge gained through instruction. *Testing Models* and *Multiple Models* were coded once in all 108 responses, both at level I (Fig. 10.1).

A theme that emerged from the analysis of prospective teachers' responses was that models are a limited way to view the world. When giving actual examples of how they used modeling in their own classrooms, many of these prospective teachers highlighted their communication of the limitation of models to their students (Fig. 10.1). This communication occurred, either through class critique of the usefulness of a model for representing concepts or through direct instruction.

In summary, of the 35 study participants, most prospective teachers provided explanations and examples related to only two aspects of models and modeling, and these were at a level I complexity. The aspects related to models as scientific thinking tools for learners, including that of testing a model and revising a model, were not clearly evident.

Aspects of Modeling (Grünkorn et al. 2014)		Evidence from student answers	Frequency (n=35)
Aspect	**Level**		
Nature of Models	**Level 1** *Models as replications of phenomenon*	"a representation of a scientific phenomenon" "simplified representation of observable phenomenon" "correct and accurate representation of a phenomenon or system." "replica, blown up atom, mini solar system, concept map, artifact that puts something big in perspective" "representation of a mechanism or phenomenon"	**27**
	Level 1 Models are Limited *Emerging theme*	"Represent some type of scientific phenomena in a visual way that puts a larger idea into a different perspective. But they are LIMITED" "I had students work with many different types of models and critique their helpfulness at the end" "I emphasized it is just a model and was a limited example"	**3**
Purpose of Models	**Level 1** *Models to describe phenomena* -help explain -pedagogical tools	"a representation of a system, process, or concept meant to communicate the idea/concept clearly" "A concept that is illustrated in a particular way so that it is easier understood by the viewer ". "They provide an opportunity to visual(ize) phenomena that can't be seen or to explain observed phenomena from the natural world". "something that describes a scientific idea (usually in visual format)"	**21**
	Level 2 *Models to explain relatioships between variables.* -variables interacting in a model	"an interactive water cycle or a stream table for island migration" "computer simulation of tides and corresponding moon or drawing".	**3**
	Level 3 *Models to predict connections*	"are representations of a real phenomenon or system and they are used to simplify the complexity to easily predict or explain the phenomenon or system."	**1**

Fig. 10.1 Representative examples of student responses coded for modeling competence

	between variables		
Changing Models	**Level 2** *Models revised based on new knowledge* -revise while learning	"models help to identify misconceptions. It is beneficial to have students come back to and revise models over time." "Revising models is a great practice to further understandings." "scientific models can and should be revised by students as they gain more knowledge of the different phenomena"	**4**
Multiple Models	**Level 1** *Several models for one phenomena differing in materials and dimensions*	"I showed many different models of the same molecule then allowed them to draw their own molecules using a model they liked best"	**1**
Testing Models	**Level 1** *Testing the model for functionality*	"We modeled a hand using straws, fishing line, and tape. Then we were able to test our models."	**1**

Fig. 10.1 (continued)

10.5 Discussion of the Study Findings

Despite the emphasis by the course instructors on inquiry/practices during the class, the majority of prospective teachers held the view that a model is a primarily a pedagogical tool, a medium rather than a model as a method for students to make sense of phenomena (Upmeier zu Belzen & Krüger, 2010). Participants viewed a model as a way to teach facts by describing or representing phenomena. Prospective teachers recognized the function of models as that of describing and representing phenomena, but did not view using models as mirroring scientific methods. In other words, these new teachers understood models *of* something but not models *for* something (Gouvea & Passmore, 2017). In addition to low complexity in their understanding, these prospective teachers lacked awareness of the multiple aspects of modeling.

Grünkorn et al. (2014) conducted a similar analysis of responses using the FMC. In their study, 1177 seven to tenth grade students completed a 15-question survey about models. The survey aligned three questions per each aspect in the framework. Responses were open and researchers coded for each competence aspect and level, as we did above. Higher frequencies in levels I and II than in level

III for each aspect were observed from their analysis, similar to our findings. Our prospective teachers performed similarly on modeling competence to the tenth grade students in the Grünkorn et al. (2014) study. We evaluated our participants' responses using the revised framework proposed by Grünkorn et al. (2014, p. 26), and the coded levels remained the same. It appeared our prospective teachers were products of their education experiences coming up through the various school grades, with no changes during their college level science course experiences.

Analyses of the data suggested these prospective teachers were inferring that, because models can be false or revisable, they are limited in their usefulness. This view contrasts with one of higher competence, that models can be falsifiable and adapted, and it is this aspect that makes models tools for the development of scientific knowledge. The participants' views suggest that models are static and cannot be changed which is consistent with novice perspectives (Crawford & Cullin, 2004; Grünkorn et al., 2014).

Prospective teachers' limited understanding of models seems to affect their beliefs about the usefulness of models by scientists and importance for the teaching of both science concepts and *practice*. Further these beliefs held strong while participating in the University's pedagogical model instruction. Many prospective teachers felt unsupported in their classroom placement, believing there was a disconnect between the teaching at the University and the realities of the classroom. This demonstrates the influence of a context (Vygotsky, 1978) in which models are majorly viewed as media instead of methods (Grünkorn et al., 2014). Prospective teachers, once in the classroom, will most likely pass these beliefs onto their students, therefore perpetuating this inadequate conception of the nature of models and leading to a mistrust of scientific evidence and knowledge (Crawford & Cullin, 2004, 2005). Focusing on prospective teachers' understanding of models and their ability to effectively teach them to their students should be of upmost importance for our University teacher education programs as it can have a direct influence on school culture.

In their capstone teacher preparation course, these prospective teachers had been offered opportunities to read articles on teaching about models and modeling, to have seminar discussions with their peers, to write reflectively, and were encouraged to teach their own students about models and modeling. Yet, there was limited empirical evidence most of them demonstrated modeling competence that would position their future teaching to include teaching students about all aspects of models and modeling in a robust way. It appears that prospective teachers, as well as science school students, need more authentic experiences with modeling that are aimed at a level III complexity (Chap. 1). While a model is not a perfect system for understanding a phenomenon, and by the very nature of the practice, may be limited, a model is consistent with the characteristics of scientific inquiry and, like other ways of knowing in the field of science, leads to valuable knowledge.

10.5.1 Possibilities of Professional Development for Enhancing Teachers' Modeling Competence

Given the empirical findings of the study of prospective teachers described above, it is important to consider how to support all science teachers, as they enter the teaching field and as they continue to teach. Designing teacher professional development programs should take into account how teachers learn in similar ways to their own students, using a socio-cultural perspective. In other words, teacher learning involves eliciting prior knowledge, building on one's experiences, gaining new experiences and reflecting on previous knowledge and views, in collaboration with others.

10.5.2 Example of a Successful Teacher Development Program

The Fossil Finders project (Crawford, 2012) is an example of an effective professional development program supporting teachers' views and teaching children about scientific practices. In this program we immersed teachers of 10–15 year old children in gathering, analyzing and interpreting data, and in creating models of the distant past, specifically of the Devonian, using authentic fossil data. One of the aspects of this professional development program involves earth sciences. To the best of our knowledge there are few studies in the literature using earth sciences as a context related to students' and teachers' use of models and understandings of models and modeling.

10.5.3 Context of the Program

The design of the program was based on a socio-cultural learning perspective. During 6 days in each of two summers, we immersed a total of 30 secondary science teaches in an authentic scientific investigation, in this case in the work of paleontologists, creating a model of what the past environment might have been 280 million years ago. The teachers would later engage their own students in the same scientific investigation, creating a context for teaching their students about important key science concepts and principles, scientific practices and nature of science. During the program teachers worked collaboratively with their peers, science teachers, educators, and scientists in collecting samples of rock from a road cut in upstate New York State. The samples were collected from different horizons in the road cut (along a vertical line), related to age of the rock. Teachers first found fossils in the collected samples, and then learned how to identify the fossils to the taxa level, including brachiopods, clams, crinoids, cephalopods. Teachers collected other important fossil data, including color of the rock, fragmentation of the fossils, and size, including length and width. The teachers learned how to make inferences about the past environment using all the data collected, and how to compare these data to an aggregate database. A nearby museum provided a site for teachers to study fossils from different eras. Teachers also were given opportunity through reflection, to connect the various aspects of the Fossil Finders investigation with what paleontologists do, and aspects of the nature of science, including creativity, subjectivity, and that models may change. The following year the teachers engaged their students in this authentic investigation, with support from the teacher educators and scientists. One of the features of the authentic investigation was to create a model to predict how populations of organisms in the shallow Devonian sea may have changed in response to changes in the ancient environment.

10.5.4 Results of the Professional Development Program

Data included pre-posttests of teachers' views of science. In addition, researchers collected classroom videotapes of approximately 2 weeks of lessons for each teacher participant. During analyses of the teachers' classroom lessons, pre-post questionnaires, and interviews, we determined most of the teacher participants enhanced their understandings of how scientists work and use evidence and logic to develop scientific models (Capps & Crawford, 2013). During the professional development sessions, we identified incidents when teachers experienced the messiness of science, and scientists were able to help them recognize that changing a research question, or revising a model, connects with the real work of paleontologists. The Fossil Finders professional development program aligns with best practices of supporting teachers (Capps, Crawford & Constas, 2012). In the professional development program, we aimed to model the kinds of interactions between teacher and students that offer opportunity to engage in scientific practices, including investigating and grappling with data, developing and using scientific models, analyzing and interpreting data, constructing explanations, and engaging in argument from evidence, and to understand that science is not absolute and there is no *one* scientific method (Crawford & Jordan, 2013).

10.5.5 Implications for Pre-service Teacher Educators and Professional Developers

> We must either accept that different conceptions of knowledge could develop in the context of different practices or suppose that there is some subset of practices belonging to all knowledge-productive practices. (Longino, 1990, p. 19)

Different contexts of practice lead to different types of knowledge. *Multiple models*, one of the aspects for modeling, demonstrates that models can be variable for a singular phenomenon (Upmeier zu Belzen & Krüger, 2010). These multiple models can come from a variety of understandings and viewpoints that are used to construct a more holistic understanding of the phenomena we observe. In the study reported above on prospective science teachers, the teachers viewed models as primarily fixed representations of fixed phenomena. This limited perspective of models is concerning, as a major aspect of modeling is the variety and adaptability used for knowledge-making (Gilbert 2004). It is important for teachers and students to understand the role of scientific models. Only if teachers themselves understand the epistemic aspects of models and modeling will true engagement of students in the epistemic aspects of modeling occur. The practices of science involve using models to gain understanding of the natural world. Associated with science is the recognition that there is value in holding multiple and alternative perspectives. To fully understand the uses of modeling one must first recognize science as situated in contexts that allow it to shift and change over time, and recognize that there is value in multiple and alternative perspectives. As such, models are a means to test and adapt to multiple content areas and contexts for learning. This is especially important for K-12 students as they come from diverse backgrounds, cultures, and understandings that will factor into their context of learning (Lee & Fradd, 1998).

Effective professional development should strive to support teachers in teaching the nature of science, including how engaging in the dynamic aspects of scientific models help us develop knowledge about the natural world. Teachers must have a deep understanding of all aspects of models, not just a few aspects (i.e. Justi & Gilbert, 2002, Justi & Gilbert, 2003). During teacher education and professional development, it will be important for teachers to actively reflect on their own knowledge and their teaching of models and modeling. Figure 10.2 offers a framework of how teachers can actively engage in inquiry, building and using models and reflecting on modeling and the teaching of modeling. Each cycle incorporates investigation, construction of a model and reflection on the model, and these cycles can occur iteratively. The reflection aspect includes explicit thinking about epistemology.

Identifying the centrality of scientific models and modeling and advocating their teaching in science classrooms is one step towards enhancing the teaching of school science. The next important step is ensuring teachers can effectively carry out this kind of instruction in classrooms. In reality, prospective teachers' lessons often begin, not with a question that might motivate children eliciting their mental models and/or building scientific models, but with a list of scientific terms and definitions, albeit these might be embellished with images from the Internet (Crawford, 2007). Anecdotally, prospective teachers reported they were very reluctant to prepare and

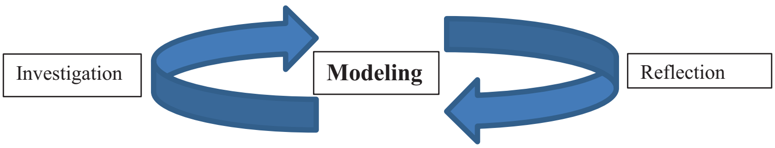

Fig. 10.2 Dual cycles of investigation leading to modeling and reflection on modeling

teach lessons rich in inquiry and use of models. They cited many roadblocks. Common responses were, "my mentor teacher told me we do not have the time to spend doing inquiry-based lessons. There is too much to cover. If it is not on the state assessment test, we cannot spend time on it" (Personal communication with prospective teachers in southeastern state, USA, October 2015).

In summary, science teacher educators and policymakers in all countries cannot afford to overlook the importance of investing in robust and carefully designed science teacher education programs and professional development opportunities, involving sustained and meaningful experiences related to developing teachers' modeling competence. Ultimately, engagement in all aspects of models and modeling by teachers will contribute to young people developing critical thinking skills and scientific literacy, useful to citizens in a world in which decisions count related to environmental crises.

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