Examination of pre-service physics teachers' epistemologies of scientific models and their model formation during model-based inquiry process

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Contents

Abstract

The purpose of this study was to evaluate pre-service teachers' epistemologies of scientific models and their model formation in a model-based inquiry environment. Theoretical underpinnings of this paper are the following: Pre-service teachers'

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epistemologies of models are structured as their beliefs, can be reshaped by instructional experiences, and may have relationship with their practice i.e. model building. One group pre-test post-test experimental design using quantitative and qualitative research methods was carried out for the study. Correlational research design was also used. The conclusions drawn from the study are as follows: First, model building and formation in inquiry facilitate changes in students' epistemic reasoning around models and enrich their understanding of what a model is, what it may be used for, and how models are built and changed. Second, instructional focus on scientific models and model based investigations influences students' reconceptualization about models and supports a shift in nature, function and inquiry role of their models. As a result, students can develop models of natural phenomena, test and revise their models and gather evidence for explanations. Finally, model-based inquiry provides bridging the gap between belief and practice so that students can reflect their epistemologies into their models.

Keywords: Model-based inquiry, pre-service teachers, epistemology, model formation.

Introduction

According to Gobert and Buckley (2000), models are representations of a system to make its central features explicit. On the other hand, model formation is the construction of a model of some phenomenon by integrating pieces of information about the structure, function/behavior, and causal mechanism of the phenomenon, mapping from analogous systems or through induction (Gobert & Buckley, 2000). The scientific modeling involving construction, use, evaluation, and revision of models embedded in the inquiry process can be generally defined as the model-based inquiry (MBI) (Schwarz et al., 2009). Windschitl, Thompson and Braaten (2008a) offer MBI as an alternative vision for investigative science to capture the features of authentic science. Involving learners in modeling practices can help them build subject matter expertise, epistemological understanding, and expertise in the practices of building and evaluating scientific knowledge (Ogan-Bekiroglu, 2007; Schwarz et al., 2009). To introduce modelling successfully in science teaching requires that teachers have an appropriate understanding of nature and function of models and their role in the accreditation and dissemination of scientific knowledge.

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Most science teachers have never directly experienced authentic scientific inquiry during their education in the sciences or within teacher education programs (Hahn & Gilmer, 2000). Hence, this study aimed to evaluate pre-service teachers' epistemologies of scientific models and their model formation in a model-based inquiry environment.

Theoretical Framework

Individual conceptions of epistemology are an important area for research and may provide further insight into how individuals make meaning and how this in turn affects learning (Hofer, 2000). Some of the general views for personal epistemology derived from the particular ontological and theoretical assumptions are as follows (Hofer, 2001):

- Epistemology is developmental and thus, part of the goal of education is to foster epistemological development.
- Epistemology exists in the form of beliefs.

Beliefs, in terms of general meaning, are deeply personal, stable, rooted in vivid memories of past experiences, lie beyond individual control or knowledge, and are usually unaffected by persuasion (Nespor, 1987). Because of the complicated nature of beliefs, some researchers talked about beliefs as a system (Block & Hazelip, 1995; Fishbein & Ajzen 1975; Green, 1971; Rokeach 1968; Thompson, 1992). There is consensus that pre-service teachers' beliefs serve to constrain their knowledge and in turn their pedagogical content knowledge (Johnston & Whitenack, 1992; Kane, Sandretto, & Heath, 2002). The need for teacher education programs to identify and target existing beliefs seems to be at the core of teacher educators' tasks (Johnston & Whitenack, 1992).

"Teachers' beliefs, which are interactive with their practices, are thought to drive actions; however, experiences and reflection on action may lead to changes in and/or additions to beliefs" (Richardson, 1996, p. 104). Thompson (1992) also reveals that the relationship between beliefs and practices is dialectic, not a simple cause-effect relationship, and suggests that studies should seek to elucidate the dialectic between teachers' beliefs and practices.

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Therefore, theoretical underpinnings of this paper are the following: Pre-service teachers' epistemologies of models are structured as their beliefs, can be reshaped by instructional experiences, and may have relationship with their practice i.e. model building.

Science Teachers' Epistemologies and Views of Models and Modelling

In order to help students in learning science, Justi and Gilbert (2002b) advocate that teachers should have comprehensive understanding of the nature of a model in general, and know when, how and why the general idea of models and specific or historical models should be introduced in their classes. Based on their findings, Summers and Mant (1995) suggest that essential prerequisites for primary teachers if they are to teach astronomy are: knowledge of accurate, scientific, structural models and being able to use these models to explain and predict simple phenomena. Consequently, researchers have developed interest in teachers' understanding of models and modelling. van Driel and Verloop (1999) conducted a research in the Netherlands to map the experienced science teachers' practical knowledge with respect to models and modelling in science, in terms of the common characteristics of models, the roles, and the functions of models in science. Two instruments were used: a questionnaire with seven open items on models and modelling, which was completed by 15 teachers, and a questionnaire consisting of 32 items on a Likert-type scale, which was completed by 71 teachers. Their results indicated that the teachers shared the same general definition of models. However, the teachers' content knowledge of models and modelling proved to be limited and diverse. A group of teachers who displayed more pronounced knowledge appeared to have integrated elements of both a positivist and a social constructivist epistemological orientation in their practical knowledge. van Driel and Verloop (2002) also aimed to find teachers' knowledge of teaching and learning of models and modelling in science education. Seventy-four science teachers in the Netherlands completed the questionnaire. The results of their study indicated that teachers differed in the extent to which they use teaching activities focusing on models and modelling in science, and their knowledge of students' conceptions and abilities in this domain was either limited or not very well integrated with their knowledge of teaching activities.

Justi and Gilbert (2002b) used a semi-structured interview to enquire into the knowledge of models and modelling held by a total sample of 39 Brazilian science

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teachers working in fundamental and medium schools, student teachers, and university teachers. The teachers' ideas were organized in three groups: the status and value of models; the influences that inform the translation of these general ideas into classroom practice; and how they responded to the outcomes of students' modelling activities. The teachers generally showed an awareness of the value of models in the learning of science but not of their value in learning about science. They were also uncertain of the relationship that could exist in the classroom between various types of models. In the same research, Justi and Gilbert (2002a) also analyzed the questions around the theme "What are the knowledge and skills that a person should have in order to produce a scientific model successfully?". Their results illustrated that the participants were not aware of the 'model of modelling' framework, and they seemed to be thinking of modelling as something done primarily by scientists, or by other people who were less effective at this than scientists.

Harrison (2001) interviewed 10 experienced science teachers about their understanding of the analogical models that they used to explain science to their students. The author found that the teachers' view of modelling, taken together, satisfied "almost all the recommendations in the literature for effective model use" (Harrison, 2001, p.10). However, individually, almost half of the sample displayed a problematic level of knowledge of models and modelling. Five teachers saw a need to negotiate with their students the shared and unshared attributes of teaching models and two consistently discussed the limitations of their models. Harrison (2001) also reported that physics teachers used more models and showed greater creativity in this area, followed by biology teachers, and lastly by chemistry teachers. Reviewing of the literature indicates that teachers may have general idea of models but their knowledge of using models in teaching and learning science is limited.

Research Focusing on a Shift in Pre-Service Teachers' Understanding of Models

Pre-service science teachers' inadequate epistemologies of models directed some researchers to improve them. For example, De Jong and van Driel (2001) worked with eight pre-service chemistry teachers to improve their emphasis from exclusively teaching content to teaching about the nature of models. Although the participants discussed articles on modeling, examined model-oriented curricula, and

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collaboratively developed lessons for teaching about specific models, most of them did not come to an understanding of some of the most fundamental functions of models.

Crawford and Cullin (2004) had secondary pre-service teachers design an open-ended investigation of a plant, soil, and water system, and later build computer models of the relevant environmental phenomena. Of the 14 participants, 13 were initially classified as midlevel modelers. Consistent with other studies, the pre-service teachers viewed models as representations used by "someone who understands" to explain to "someone who doesn't." After the modeling experience, the participants shifted their thinking, from models being used by someone to explain an idea to another, to the model being considered by a “user” to understand the phenomena him- or herself. Overall, however, no participant moved from a mid-level understanding to an expert level.

Windschitl and Thompson (2006) examined 21 pre-service secondary teachers as they engaged in activities aimed at fostering their understanding of models and how models are used in inquiry. The study culminated in independent inquiries by the students, in which they were required to develop a model of a natural phenomenon, empirically test some aspect of that model, and use the results to support or revise the original model. They found that instruction could help pre-service teachers develop more sophisticated understandings of scientific models and promote incorporation of model-based lessons in their classrooms. However, they indicated that even with scaffolding, the majority of these pre-service teachers were unable to use theoretical models to ground their own empirical investigations.

Schwarz and Gwekwerere (2007) worked with 24 pre-service elementary teachers to engage them in model-based reasoning and move a majority toward their own model-based lesson designs. Though some participants used models in their lessons in ways inconsistent with model-centered inquiry, the researchers experienced some success using an “engage, investigate, model, and apply” framework.

According to Windschitl and Thompson (2006), undergraduate experiences do little to advance the idea of models beyond that of acting as pedagogical props. Schwarz, Meyer and Sharma (2007) claim that the depth of students' understanding of the nature of models is likely to arise or emerge by having students deeply engage in

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modeling with a variety of inquiry tasks. Research results indicate the need for more robust instructional designs that include opportunities to work with models in varied and mutually reinforcing contexts, and routinely connect the principles of model-based inquiry to classroom practice (Windschitl, Thompson & Braaten, 2008b). However, there is not much research on engaging pre-service science teachers in inquiry with an emphasize on modelling. The participants of a research done by Akerson and her colleagues (2009) were 10 practicing elementary teachers participating a K-6 professional development program that emphasized scientific inquiry and nature of science within the theme of scientific modeling. During the 2-week summer workshop and follow up school year workshops, the instruction modeled a 5-E learning cycle approach. Scientific modeling proved useful in illustrating the distinction between observation and inference as teachers were asked to make observations and use their inferences to make their own models. Teachers added the use of mathematical formulas to their views of scientific modeling. Moreover, they used models mostly at the elaboration stage of the learning cycle, finding it a good place to ask students to apply their scientific knowledge.

Whereas there has been substantial amount of research regarding the effects of model-based instruction on pre-service teachers' conceptions of models, research focusing on pre-service science teachers' epistemologies in a model-based inquiry environment and looking for a relationship between their epistemologies and their model building is not ample.

The Purposes of the Study

To optimize classroom learning around epistemically rich forms of model-based inquiry, teachers need a sophisticated understanding of the nature of scientific models as well as how they are used in authentic inquiry (Windschitl et al., 2008b). Pre-service science teachers' epistemologies of models and modelling is crucial because it may influence the way they implement modelling in their future classrooms. Specific activities may be designed to anticipate pre-service teachers' epistemological orientations. Therefore, teacher education courses need to pay more attention to models and modelling in science education (Justi & Gilbert, 2001).

The following research questions put a light on this research: 1) Does model-based inquiry influence pre-service physics teachers' epistemologies of nature and function

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of models, 2) Does model-based inquiry have impact on pre-service physics teachers' models that they created, 3) Is there any relationship between pre-service teachers' epistemologies of models and their model formation?

Methodology

One group pre-test post-test experimental design using quantitative and qualitative research methods was carried out for this study (Krathwohl, 1997) to assess the effects of model-based inquiry on pre-service physics teachers' epistemologies of models and on the models they constructed. Moreover, correlational research design was used to determine any relation between participants' epistemologies of nature and function of models and their model creation. Changes in participants' epistemologies as well as in their models and a possible relationship between the two were examined statistically for the quantitative aspect of the study. On the other hand, the purposes of the qualitative part were to evaluate participants' models and to provide justification for the quantitative research.

Participants and Settings

Participants of this study were 11 senior pre-service physics teachers, six of whom were females. Ages of the participants ranged from 22 to 24 years. The instructional strategy in the class was model-based inquiry (MBI). Anonymity was preserved by using codes for the participants; therefore, P1 through P11 represented the pre-service teachers. The study took place in an elective course called Conceptual Physics in the physics teacher education program at a state university. The course aimed to develop participants' conceptual knowledge of dynamics and help them reformulate their views of effective science teaching. The pre-service physics teachers took the course for 2 h/week and worked as groups when it was necessary. They chose their peers themselves. Hence, P1 worked with P2, P3 worked with P4, P5 worked with P6, P7 worked with P8, and P9 worked with P10 and P11. The students constructed their models and conducted experiments as groups; however, they wrote their inquiry reports individually.

Treatment and Instructional Context

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According to Chinn and Samarapungavan (2008), instruction should engage students in thinking about their beliefs and epistemology, their general understanding of causal and non-causal models; the specific entities and activities of the models they are learning, together with how these models link to phenomena; and a variety of relations with other models. Model-based inquiry is an instructional strategy whereby learners are engaged in inquiry in an effort to explore phenomena and construct and reconstruct models in light of the results of scientific investigations (Campbell, Oh & Neilson, 2012). Therefore, the pre-service teachers studied some dynamics concepts during the model-based inquiry process. Meyer-Smith and Mitchell (1991) present some reasons for the difficulty in changing pre-service teachers' beliefs such as short duration of course and critical timing of university-based experiences. Hence, the duration of the model-based inquiry instruction was one semester. Since the participants had not had any experience with modelling in inquiry before, the instruction in the first and second weeks of the semester focused on the implementation of model-based inquiry as an instructional method. The participants were requested to generate initial models, develop inquiry questions, propose hypotheses, do investigations and conduct experiments to test their models. They constructed three dimensional models, revised their models and used them for explanations. The instructional context is demonstrated week by week in Table 1.

Table 1. Model-based inquiry instruction.

Weeks	Model-Based Inquiry
1-2	Pre-administration of the model epistemology questionnaire. Model-Based Inquiry (MBI) was explained as a teaching strategy and some cases were given as examples.
4-8	MBI was implemented for the first activity. Worksheet for the first activity was distributed. The students were started to work as groups. They generated initial models suggested processes or structures potentially explanatory of the phenomenon. They developed inquiry questions in tandem with their models. The students stated potential relationships between variables and used their models to propose hypotheses. They conducted experiments and took measurements to test the models. Experiments were related to an inclined plane. The students also used models to collect data and evaluated the hypotheses. They modified their models if it was necessary. They started to write their inquiry reports. The students used patterns in the data and models to explain the phenomenon. They assessed and revised their models by taking into account additional evidence or aspects of the phenomenon. The students presented their final models and discussed how their models could generate different hypothesis. They argued about if their models could apply to other phenomena. They handed their inquiry reports in.

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9-13	MBI was implemented for the second activity. The students followed the same procedure they did for the first activity. However, this time experiments were related to free fall of various objects with different features in various mediums.
14	Post-administration of the model epistemology questionnaire.

The participants worked on two inquiry activities during the course period. Each activity lasted five weeks. The first activity was about a half pipe in a skate park. The question was as follows: The person sitting on the deck of the half pipe as shown in the picture wants to send a ball to his friend sitting on the opposite deck by dragging it in the pipe instead of throwing the ball. If amplitude, transition and flat bottom of the half-pipe can be changed, how can the person send the ball as fast as possible? The second activity was based on the difference between Galileo's and Aristotle's ideas about falling objects. The participants were given a discussion in an unfinished dialogue among three people and asked to explain who was right and who was not right by providing evidence. They were also demanded to complete the unfinished dialogue. The dialogue was taken from the book written by Galileo Galilei, which was translated by Crew and Salvio in 1914. The model-based inquiry instruction has explained in more detailed in Arslan-Buyruk and Ogan-Bekiroglu (2018).

Role of the Researchers

The authors of this paper are physics educators. The first author was the instructor of the course; therefore, she had two roles. One was as a teacher and the other one was as a researcher. Two researchers prepared the lesson plans and worksheets together. The first author observed and guided the groups, started and led discussions, and prevented irrelevant talk during the activities. Both authors had roles in planning the activities, conducting the research, and analyzing the data.

Data Collection Methods

The pre-service teachers' epistemologies of nature and function of models were assessed with the help of the epistemology questionnaire used by Gobert and Discenna (1997) adapted from Grosslight et al (1991). The purpose of the questionnaire is to describe students' understanding of what a model is and what it is used for. The questionnaire has nine open-ended questions. The first three questions aim to find out what students' understanding of a model is and how it is used (What comes to mind when you hear the word model? How would you describe a model to

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someone who didn't know what a model is? What are models used for?). The following two questions seek to assess students' understanding of how the word model might relate to the water cycle model presented (Students are given a diagrammatic model of the water cycle and asked: Can this be considered a model? Why?, Could you use this as a model? If so, how?). Finally, the last four questions ask about how models are designed and created, whether a model could be changed, and if there could be multiple models of the same phenomena (How close does a model have to be to the real thing? How do you know what to include in a model? Can scientists have more than one model for the same thing? Are there instances that would require this model or any model to be changed? If yes, what are they?). The questionnaire was administered to the students before and after the model-based inquiry instruction.

The participants' initial and final models were evaluated by observing and asking questions to them. Their models were examined from three perspectives: the nature of models, the function of models, and the role of models in inquiry based on the rubric developed by Windschitl and his colleagues (2008b).

Data Analysis

Analysis of Model Epistemologies: The participants' model epistemologies were analyzed based on a conceptualization of how experts perceive models determined in the literature (Crawford & Cullin, 2004; Justi & Gilbert, 2002; Schwartz & Lederman, 2008; Windschitl, Thompson & Braaten, 2008b). According to the expert view, models can represent a system of ideas with explanatory power for some process or event, models can be created in different representational modes for different purposes (e.g., a concept map vs. a pictorial drawing), and a phenomenon can be conceptualized through models in different ways (e.g., a caloric vs. kinetic model of heat transfer for example). Moreover, applying a model to real-world circumstances must take into account the logical limits of the model as well as any underlying assumptions used to build the model. Regarding the function of models, models can be used to facilitate novel insights into a natural or mathematical system, and how they are used to predict or explain events. Models cannot be completely accurate and are almost always tentative, in the sense that they are open to further revision and development. In addition, scientists can hold more than one model for

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the same phenomenon depending on the context, on the purpose of the scientific research, and on the perspective of the scientist.

The pre-service physics teachers' responses to the epistemology questionnaire were categorized as "sophisticated", "transitional", and "naïve" after codes were identified from their answers. Sophisticated epistemologies are aligned with expert views. Therefore, when the students answered with a naive conception of models, e.g., that models are merely small replicas of objects, their responses were categorized as naïve while their responses were categorized as sophisticated when they answered with an advanced conception of models, e.g., that models are used to reflect or explain how something functions. Specifically, similar to the Gobert and Discenna (1997)'s scoring, the students who viewed models as physical objects such as model airplanes or cars were classified as naïve whereas the students who explained models as representations of an idea or how things worked and were used to instruct, show, understand or explain how something worked were classified as sophisticated. In the case of the diagram of the water cycle, the students who stated that the water cycle model could be used as a model to show how the water cycle worked were considered as sophisticated. Regarding model building and designing, the students whose answers reflected an understanding of models as representations were considered as sophisticated. For example, the students' understanding of how close a model had to be to the real thing and what to include when making a model originated from the idea that the model had to be identical to the real object (physical view) to the model had to be close enough to be able to understand the idea (abstract view). The students having sophisticated answers had the understanding that models were a representation and tended to answer that there were multiple models and that models were changeable. Whereas, the students having naïve responses believed that models were exact replicas of the "real" thing focused on physical differences. The students' responses were categorized as transitional if they were in between naïve and sophisticated along this continuum.

In order to determine the pre-service physics teachers' epistemologies and to do non-parametric statistical analyses between their pre- and post-epistemologies, their responses were scored. Accordingly, naïve responses were scored as "1", transitional responses were scored as "2", and sophisticated responses were sored as "3". Mean value of nine scores gathered from nine responses of each student was calculated to assign the category to the student's epistemology. Since the mean values ranged from

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1 to 3, mean values between 1 - 1.66 were categorized as naïve epistemology, mean values between 1.67 – 2.33 were categorized as transitional epistemology, and mean values between 2.34 - 3 were categorized as sophisticated epistemology.

Analysis of Models: The students' models they created were analyzed based on the rubric whose criteria are listed in Table 2. Their models were categorized as "congruent with experts' models", "congruent with intermediate models", and "congruent with novices' models". Their models were scored to do non-parametric statistical analyses between participants' initial and final models. Thus, a score of "3" represented models that were congruent with those of experts, a score of "2" represented an intermediate level of models, and a score of "1" represented models that were congruent with those of novices. Mean value of three scores gathered from three perspectives (the nature of models, the function of models, and the role of models in inquiry) of each model was calculated. Since the models' mean values ranged from 1 to 3, mean values between 1 - 1.66 were categorized as novice, mean values between 1.67 – 2.33 were categorized as intermediate, and mean values between 2.34 - 3 were categorized as expert.

Table 2. Criteria for model evaluation (Windschitl, Thompson & Braaten, 2008b).

Nature of Models	Function of Models	Role of Models in Inquiry
"3" Congruent with experts' models		
Can portray conceptual/theoretical as well as observable processes and relationships. Represent ideas rather than "things." Models fallible in concept because they are based on interpretation and inference. Models have logical limits and underlying assumptions. Models can differ not only because of representational modes, but	Tools to advance scientific ideas rather than only being a product of inquiry are generalizable, can be used to predict. Tools to advance scientific ideas rather than only being a product of inquiry allow novel insights into relationships, and help generate questions for inquiry.	Research questions are conceived of within the context of a model. Hypotheses are parts of models that will be tested. Models are revised through argument that uses data and logic, must be consistent with evidence, other models, theories. Empirical data can be used to argue for theoretical "pieces" (structures or processes) of models.

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because a phenomenon is totally reconceptualized.		Models can change not only as result of empirical "fine-tuning" but also because target phenomenon is reconceptualized in new way.
"2" Intermediate models		
Models portray processes and systems that may not be directly observable, but are taken to be real. Models can take form of mathematical representation or set of rules. Models of same thing can be different because there are different modes of representation.	Facilitates understanding, helps others to understand what an expert knows. Are generalizable, used to describe different situations. Helps analyze effects/variables of some complicated system.	Scientific inquiry is done first, then create a model based on data. Models can help one think of things to investigate. Hypotheses are models. Data can be collected from models themselves. It is important to collect data on actual phenomenon (rather than exclusively from a model) if possible. Models are changed only if they do not match/predict data.
"1" Congruent with novices' models		
Models are pictorial or physical replications of "things" considered to be real. Object of model may be too small, too large or inaccessible to direct observation. Relation of model to thing being modeled: object of model is more complex. Models can be different from one another because of different "looks" at the object.	To simplify, illustrate, show	Model development not recognized as part of scientific inquiry; models function only to illustrate, simplify, help communicate ideas. Hypotheses are "best guesses" from unspecified background knowledge. Relationships between empirical observations and theory unspecified. Fact that data can be collected from models themselves is unacknowledged. Argument may be synonymous with "conclusions;" directed toward determining if questions are answered rather than using patterns in data to support or refute models.

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Analysis of A Relationship between Epistemologies and Models: Spearman's rank correlation coefficient test was performed to look for a relationship between the participants' epistemologies of nature and function of models and their constructed models.

Results and Discussion

The Pre-Service Physics Teachers' Epistemologies of Nature and Function of Models

One table was prepared for each open-ended question based on the codes gathered from the students' responses. Three out of nine tables are presented here due to the page limitation. Table 3 shows the codes gathered from the pre-service teachers' responses about what the models are used for before and after the model-based inquiry instruction. While six students had thought that models were used for perspicuity before the MBI, three more students achieved this idea after the MBI. Even though one student (P4) had claimed that models were used for representation of a reality before the MBI, she changed her mind after the instruction and stated that models were used for perspicuity. Moreover, P10 and P11 expanded their views after the instruction and wrote that models were also used for construction of new models.

Table 3. Codes gathered from the pre-service teachers' responses to "What are models used for?".

	Before the MBI				**After the MBI**			
P / Codes	Perspicuity Making sense	Concretization	Representation of a reality	Explanation of scientific claims	Perspicuity Making sense	Concretization	Explanation of scientific claims	Construction of new models
P1	X				X			
P2	X					X	X	
P3	X	X			X	X		
P4			X		X			
P5	X			X	X			
P6				X	X			

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P7	X				X	X		
P8	X				X	X		
P9	X				X			
P10				X			X	X
P11				X			X	X
Total Frequency	6	2	1	4	9	3	3	2

P: Participants

The codes based on the students' responses about what to include in a model are presented in Table 4. Whereas three students had assumed that inventions were included in a model before the MBI, they changed their thoughts after the MBI. Only P2, P4 and P5 had written that a model comprised aspects of a subject before the instruction, four more students shared this view after the instruction. In addition, six students explored that a model could contain theory, hypothesis and formulas after the MBI.

Table 4. Codes gathered from the pre-service teachers' responses to "How do you know what to include in a model?

	Before the MBI				**After the MBI**			
P / Codes	Visuality	Inventions	Aspects of a subject	Relationships	Visuality	Aspects of a subject	Theory, hypothesis, formulas	Variables
P1	X				X	X		X
P2			X		X	X	X	
P3	X				X			
P4			X			X	X	
P5		X	X		X	X	X	
P6		X			X		X	
P7					X			
P8			X		X	X	X	

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P9	X				X	X		
P10		X				X	X	
P11	X			X	X			X
Total Frequency	4	3	4	1	9	7	6	2

P: Participants

According to Table 5, P1 had believed that models did not change in time whereas P3, P4 and P5 were not sure about this before the modelling activities. After they had experiences with model construction, they all believed that models could change. Four students realized that models could change because of tentativeness of science and six students understood that models could change because of scientific research and technology.

Table 5. Codes gathered from the pre-service teachers' responses to "Are there instances that would require this model or any model to be changed? If yes, what are they?.

	Before the MBI					**After the MBI**		
P / Codes	Yes, models of atoms changed	Yes, if the subject is changed	Yes, when new scientific discoveries happen	Not sure	No	Yes, models of atoms changed	Yes, because of tentativeness of science	Yes, because of scientific research and technology
P1					X	X		
P2	X					X		X
P3				X		X		
P4				X			X	X
P5				X				X
P6			X			X		X
P7			X				X	
P8			X				X	
P9		X				X		X

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P10	X					X		X
P11	X		X			X	X	
Total Frequency	3	1	4	3	1	7	4	6

P: Participants

Table 6 illustrates that all the pre-service physics teachers improved their epistemologies after the model-based inquiry instruction. Yet, due to the fact that increases in the epistemology scores of P4, P7, P8, and P9 were less than 0.66, these students' epistemologies stayed in the same category.

Table 6. The pre-service teachers' model epistemologies before and after the MBI

	Before the MBI		After the MBI		
Participants	**Mean Values**	**Category**	**Mean Values**	**Category**	**Differences in mean values**
P1	1.29	Naïve	2.17	Transitional	0.88
P2	1.71	Transitional	3.00	Sophisticated	1.29
P3	1.43	Naïve	2.00	Transitional	0.57
P4	1.86	Transitional	2.17	Transitional	0.31
P5	1.14	Naïve	2.57	Sophisticated	1.43
P6	2.00	Transitional	2.71	Sophisticated	0.71
P7	1.71	Transitional	2.17	Transitional	0.46
P8	1.86	Transitional	2.29	Transitional	0.43
P9	1.14	Naïve	1.54	Naïve	0.40
P10	2.43	Sophisticated	2.57	Sophisticated	0.14
P11	2.00	Transitional	2.57	Sophisticated	0.57
Overall Mean	1.69	Transitional	2.34	Sophisticated	0.65

For example, P4's belief about models stayed in the transitional stance. Her answers to the question "What comes to mind when you hear the word model?" before and after the instruction were as follows:

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> "What comes to my mind when I hear the world model is concrete figure of an object whose image in my brain is abstract" (before).
>
> "Model is the mental design of a real phenomenon. For example, a model of the atom helps us to examine the atom" (after).
>
> She wrote the following statements about whether a model could change:
>
> "I do not have much idea about the examples of models that changed in time. However, if aspects of the things that a model represents change, the model may change" (before).
>
> "Many ideas can change and develop in time. New findings can be added to a finding, so that it can be changed and developed. For example, Galileo measured time with water clock in his free fall experiment but we used chronometer to measure time in our experiment" (after).

On the other hand, P9 had had naïve epistemologies in the beginning and did not show much improvement. She had thought models could only be three dimensional. Her definition of models before the MBI implementation was explanation of a subject by using an object. Her definition was more explanatory but unfortunately not sophisticated after the implementation:

> "Model is a copy of a case or a phenomenon that needs to be explained. This copy should be similar to the real thing. Making scale models is modelling. Photographs are also models" (after).
>
> Her responses to the question about water cycle had inconsistencies. She did not explain why water cycle was a model.
>
> "Water cycle may count as a model but models do not include explanations. Models are explanations themselves" (before).
>
> "Yes, water cycle is a scientific model. My imagination can also count as a model" (after).

Before the MBI, four students (P1, P3, P5, and P9) had held naive epistemologies of nature and function of models, whereas one student (P10) had possessed

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sophisticated epistemology. However, only P9 kept her naïve epistemologies and five students (P2, P5, P6, P10, and P11) could develop sophisticated epistemologies after they were introduced with modelling. P2 and P5 were the ones who performed the highest progress.

For example, P2 had not answered to the question about what to include in a model. However, after he had some experiences with modelling he could wrote that models could include hypothesis, formulas, equations, schemes, and diagrams. He also expanded his views about why models were used for:

> "Models are used for making something concrete" (before).
>
> "Models are used to explain a scientific phenomenon more easily and more effectively" (after).

The progress in P5' model epistemology can be seen from her responses. For instance, she did not recognize water cycle as a model in the beginning of the instruction because she had assumed that the cycle was a clarification but a model was a way of proofing something. Nevertheless, at the end of the MBI instruction she stated that:

> "It is hard to observe the cycle of water; hence, this cycle can be shown by using models such as pictures and animations so that students' understanding can be reinforced" (after).
>
> P5's ideas about tentative nature of models became more comprehensive after the MBI implementation.
>
> "Models can change in time but I cannot give a specific example for that. If the method changes the model changes" (before).
>
> "Scientific models are tentative. The model that was used to explain the motion was F=m.v. However, it has been changed to F=m.a. This model may also change in the future" (after).

The whole participants' overall mean value increased from 1.69 to 2.34 showing that their transitional epistemologies enhanced to sophisticated epistemologies. The results of Wilcoxon signed-rank test for the pre-service teachers' epistemologies

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before and after the MBI were in the expected direction (z = -2.936) and sum of positive ranks was significantly higher than the sum of negative ranks (p

Table 7. Results of the Wilcoxson signed-rank test for the epistemologies before and after the MBI

		N	Mean Ranks	Sum of Ranks	z	p
Post Epistemologies-Pre Epistemologies	Negative	0	0.00	0.00	-2.936	.003
	Positive	11	6.00	66.00		
	Ties	0				
	Total	11				

The Pre-Service Physics Teachers' Models

The participants created two models in two activities through the model-based inquiry instruction. They started the inquiry with their initial models and at the end of the activity, they finalized their models. Table 8 reflects how their models changed in terms of nature of models, function of models, and role of models in inquiry. Regarding Table 8, the first, the second and the third groups generated better final models than their initial models during the first activity. Besides, the second group's final model was compatible with experts' models. Their initial model which was in intermediate level in the category of roles of models in inquiry could test more than one hypotheses; thus, they had written more than one research question. They had thought that if they increased temperature they would decreased friction. In order to minimalize the energy lost they had kept the horizontal plane short. The second group's initial model received the score of 2 in the nature of models category because the model included both observable and non-observable processes. Their model also obtained the score of 2 in the function of models category since it could analyze a complex system. Later, the second group revised their model because it could not test some hypothesis about a relationship between temperature and friction. Their final model was congruent with experts' models in all categories because they wanted to use their models for generalizations, they examined friction in molecular level, their research questions were conceived of within their model, and they argued about theoretical structures. Figure 1 presents the second group's initial and final models.

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Table 8. Criteria for model evaluation (Windschitl, Thompson & Braaten, 2008b).

	First Activity				**Second Activity**			
	Initial Model 1		**Final Model 1**		**Initial Model 2**		**Final Model 2**	
Groups' Numbers and Members	**Mean Values**	**Category**	**Mean Values**	**Category**	**Mean Values**	**Category**	**Mean Values**	**Category**
1: P1, P2	1	Novice	2	Intermediate	2	Intermediate	2.33	Intermediate
2: P3, P4	2	Intermediate	3	Expert	2	Intermediate	2	Intermediate
3: P5, P6	1.33	Novice	2.33	Intermediate	2	Intermediate	2.33	Intermediate
4: P7, P8	1	Novice	1	Novice	1	Novice	1.66	Novice
5: P9, P10, P11	1	Novice	1	Novice	2	Intermediate	2.33	Intermediate
Overall Mean	1.26	Novice	1.86	Intermediate	1.8	Intermediate	2.13	Intermediate

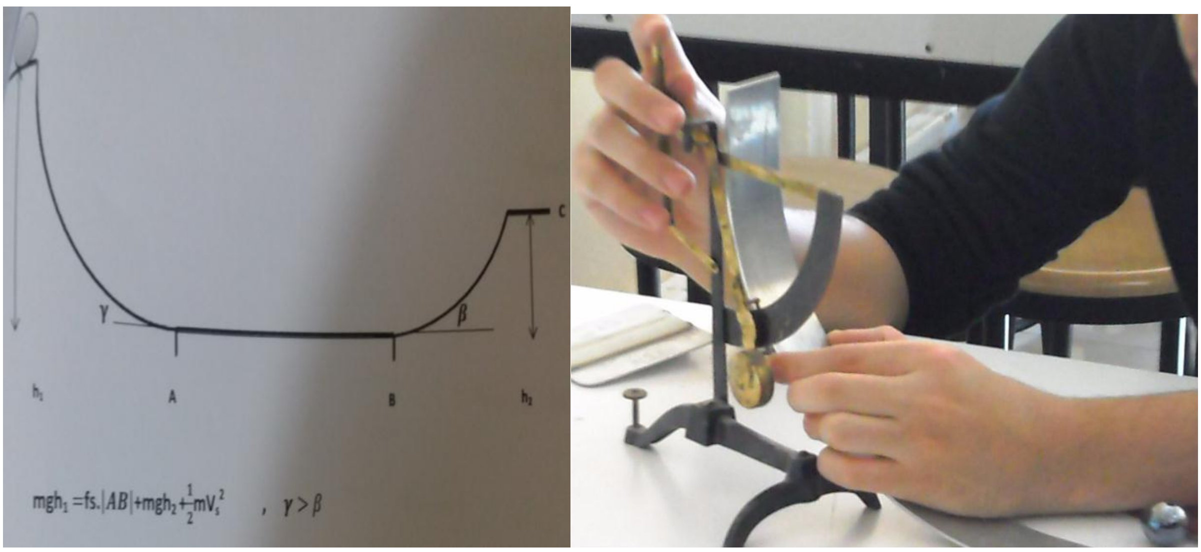

Figure 1. The second group's initial and final models.

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However, there was not much revision between the initial and final models of the fourth and the fifth groups during the first activity. For instance, regarding the fourth group, there were inconsistencies between theoretical pieces of their model and their constructed model. While their initial model consisted of mathematical models of potential and kinetic energy, they only measured time in their final model. Their purpose of modeling was just simplification and visualization. Consequently, their final model did not have much function. Although they stated that they neglected friction, there was not any proof for that in their model. Moreover, their model did not allow for inquiry.

The results of Wilcoxon signed-rank test were in the expected direction (z = -2.449) and sum of positive ranks was significantly higher than the sum of negative ranks (p

Table 9. Results of the Wilcoxon signed-rank test for the initial and final models

		N	Mean Ranks	Sum of Ranks	z	p
Final Model 1- Initial Model 1	Negative Positive Ties Total	0 6 5 11	.00 3.50	.00 21.00	-2.449	.014
		N	**Mean Ranks**	**Sum of Ranks**	**z**	**p**
Final Model 2 - Initial Model 2	Negative Positive Ties Total	0 9 2 11	.00 5.00	.00 45.00	-2.810	.005
		N	**Mean Ranks**	**Sum of Ranks**	**z**	**p**
Two Final Models - Two Initial Models	Negative Positive Ties Total	0 11 0 11	.00 6.00	.00 66.00	-2.958	.003

All of the groups, except for the second group, increased their models' scores when they constructed their final models during the second activity (see Table 8). However, the models stayed in the same category because the differences between final models' scores and the initial models' scores were not bigger than 0.66. That is, the participants already created initial models which were good in terms of their nature,

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function and role in inquiry. With regard to the second group, there was not any change between their scores of initial and final models. Their final model neither enabled inquiry nor generalizability. Though their model allowed them to show what they already knew about free fall, it did not open for different representations.

The results of Wilcoxon signed-rank test were in the expected direction (z = -2.810) and sum of positive ranks was significantly higher than the sum of negative ranks (p

Moreover, Table 8 illustrates that the pre-service teachers' initial models for the second activity (overall mean is 1.8) were more comprehensive than their initial models for the first activity (overall mean is 1.26). Similarly, their final models for the second activity (overall mean is 2.13) were more close to experts' models than their final models for the first activity (overall mean is 1.86). The results of Wilcoxon signed-rank test were supported this finding because they were in the expected direction (z = -2.958) and sum of positive ranks was significantly higher than the sum of negative ranks (p

These findings are not much in line with the results of Windschitl and Thompson (2006) because most of the pre-service teachers in this study used models to ground their own empirical investigations. Additionally, unlike the participants of Schwartz and Gwekwerere (2007)'s study, great majority of the participants of this research recognized the role of models in inquiry.

Relationship Between Pre-service Teachers' Epistemologies of Models and Their Model Construction

In order to find if the pre-service physics teachers reflected their epistemologies to their models, Spearman's rank correlation coefficient test concerning the differences between two initial models and two final models and the differences between pre and post epistemologies was calculated. These analyses revealed significant positive high correlation between the development in the students' models they constructed and the progress in their epistemologies of models ($r = .80$, $p < 0.01$) (see Table 10). That is to say, the pre-service physics teachers could put their beliefs into their practices. While some researchers (Skott, 2001; Stipek, Givven, Salmon, & MacGyvers, 2001) advocate that the influence is from belief to practice, some (Guskey, 1986; Ruthven, 1987) argue that belief is the result of practice rather than a main influence on it. Either way, the result of this study showed consistencies between beliefs and

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practices. Comparison of Table 6 and Table 8 discloses that P1, P2, P5, and P6 made more advance in their model epistemologies than their peers made. These participants also improved their models more. Hence, it can be said that the more progression in model epistemologies requires the more quality revision in models.

Table 10. Result of Spearman's rank correlation coefficient test concerning the differences between two initial models and two final models and the differences between pre and post epistemologies

Variables	**N**	r_s	**P**
Differences of initial and final models - Differences of epistemologies	11	.80	.003

Conclusions and Implications

According to Boulter and Gilbert (2000), the modelling and models are important for three major reasons: "first, modelling and models are explicitly recognized in science and science education; second, they play a major role in the nature of science and its achievements; and third, they play a major role in technology" (p. 344). Justi and Gilbert (2002b) advocate that teachers should have the following knowledge and ability in order to help their students in learning science:

• Have a comprehensive understanding of the nature of a model in general,

• Know when, how, and why, the general idea of models and specific scientific or historical models should be introduced in their classes,

• Have the ability to develop good teaching models-those that are created with the scientific purpose of facilitating students' understanding of scientific or historical models,

• Have the skills needed to construct modelling activities in their classes.

Pre-service physics teachers involved in model-based scientific inquiry in this study to be able to enhance their epistemologies of scientific models and their model construction. This research reached the following conclusions: First, model building and formation in inquiry facilitate changes in students' epistemic reasoning around

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models and enrich their understanding of what a model is, what it may be used for, and how models are built and changed. Second, instructional focus on scientific models and model based investigations influences students' reconceptualization about models and supports a shift in nature, function and inquiry role of their models. As a result, students can develop models of natural phenomena, test and revise their models and gather evidence for explanations. Finally, model-based inquiry provides bridging the gap between belief and practice so that students can reflect their epistemologies into their models.

One limitation of this study is the research design where there was no control group. However, the participants had not had any experiences with modelling and did not have any involvement with model-based instruction in any other courses they took during the research. Another limitation is the subject. The pre-service physics teachers created models related to dynamics due to the subject of the activities. The participants' model quality and their answers to the model questionnaire during the post application might be different if the subject had been different physics subject. The current study contributes to the science education literature toward a better understanding of benefits of MBI as an instructional strategy in an authentic context. Model-based inquiry would be embedded in science teacher education programs to improve teacher candidates' knowledge about models and their modelling activities.

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