Using Model-Centered Science Instruction to Foster Students' Epistemologies in Learning with Models

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In this paper, I report on two studies – one conducted with seventh-grade science students and the other with undergraduate pre-service elementary teachers – using model-centered science curricula and instruction. In both studies, these students experienced model-centered teaching and used 12-14 week curricula in which they used models, created models, evaluated models, and reflected on the nature of models within either force and motion or astronomy topics. In the seventh-grade study, I investigated students' epistemologies about the nature of models with written assessments and clinical interviews and found evidence that modeling knowledge (epistemological understanding of models) was significantly correlated with improvement in content knowledge. Through analysis of classroom videotapes, notes, and student journals in both studies, I also found several useful contexts for promoting modeling knowledge. These contexts included engaging students in using well-designed computer-simulated dynamic models that can be useful for solving relevant problems, using and creating physical and conceptual models, reflecting on the nature of models, and evaluating models with model-specific criteria. The two different studies also indicate that different contexts and model-use elicited different epistemological views about models from the students. The seventh-grade students thought of models as abstract, more or less equivalent in value to one another, and useful for testing/exploring their own theories. The pre-service teachers thought of models as concrete/visual representations, more or less valuable depending on their accuracy and limitations, and useful for visualizing phenomena and learning the correct scientific knowledge for teaching their future students.

Introduction

In recent and not so recent history, educational researchers have advocated the use of models in science education (Brand, Rader, Carlone, & Lewis, 1998; Confrey & Doerr, 1994; Feurzeig, 1994; Gobert & Discenna, 1997; Halloun & Hestenes, 1987; Horwitz, 1999; Lehrer & Schauble, 2000; Mandinach & Cline, 1993; Mellar, Bliss, Boohan, Ogborn, & Tompsett, 1994; Papert, 1980; Penner, Giles, Lehrer & Schauble, 1997; Raghavan & Glaser, 1995; Resnick, 1999; Richards, Barowy, Levin, 1992; Sabelli, 1994; Schwarz & White, 2000; Spitulnik, Krajcik, & Soloway, 1999; Tinker, 1993; White & Frederiksen, 1998, Wilensky, 1999). Whether or not one agrees with this approach, models and modeling are frequently used as instructional tools or processes in science education. While many researchers have repeatedly proven that models can foster conceptual change, systems-thinking, and a number of other important aspects (Mandinach & Cline, 1993; Raghavan & Glaser, 1995; Resnick, 1999; Richards et al., 1992; Schwarz & White, 2000; Spitulnik et al., 1999; White & Frederiksen, 1998), we also acknowledge that value of their use is complicated. Members of this session (as well as others), hypothesize that the degree to which models can serve as effective learning tools may depend on students' epistemological understanding of models (Carey & Smith, 1993; Gobert & Discenna, 1997; Grosslight, Unger, Jay & Smith, 1991; Hammer, 1994; Schwarz & White, 2000; Smith, Maclin, Houghton & Hennessey, 2000, Songer & Linn, 1991). In other words, students' orientations about the nature of models and how they are used will effect how students use models. While many educators and researchers in science have been using models and observing the effect of student epistemologies on the quality of the learning experience, there has been little evidence directly linking the two with the exception of a few studies (Hammer, 1994; Songer & Linn, 1991).

Even if a strong relationship cannot be formally established between students' epistemologies and their model use, it may still be valuable to help students and teachers develop a general understanding of the nature of models and the process of modeling. Model-building and revising is a critical piece of science, and science students should know about and be engaged in this process. Further, if one defines science as a process of model-building, this may help learners gain a more productive epistemological orientation in understanding that scientific knowledge is a human construct and that models vary in their ability to approximate, explain, and predict real world phenomena.

Before continuing, let me define a few terms. In order to be consistent with others in this session, I use the definitions of 'epistemologies' and 'models' outlined in the session's proposal. We use the word epistemology to include people's orientations about the nature of models and how those epistemologies are used in reasoning. I also call epistemologies of models, "knowledge about the nature of models" or sometimes "metaconceptual knowledge about models." Our overall consensus is that a scientific model is some kind of representation that predicts or explains scientific phenomena and that modeling or model-based reasoning includes the processes of model creation, use, evaluation, and revision. Models can range in form from a scale model of the solar system, to computer simulations that predict how galaxies can collide, to quantitative or qualitative laws and theories like F=ma or "when no forces are acting, an object's velocity remains the same because there is nothing causing it to change."

To return to the prior argument, if we think students' epistemologies about modeling may have an important influence on science content learning, what kind of evidence can we provide for this relationship? Further, if we think that developing students' epistemologies of models may itself be valuable, what are some good ways of foster it? In other words, what are epistemologically rich contexts that might help achieve this goal?

It is the aim of this paper to present evidence from two separate studies that epistemologies of modeling may be linked to students' scientific content learning, and to provide some examples of rich educational contexts that may help students' develop their epistemologies of modeling. The first study involved seventh-grade class using 10 1/2 week model-based inquiry curriculum about force and motion. (Much of this study has been reported elsewhere, Schwarz, 1998; Schwarz & White, 2000) The second study involved pre-service elementary teachers using model-centered science instruction and curriculum within the context of astronomy and force and motion. (Model-centered science instruction is instruction in which model use, creation, and evaluation lies at the core of the science teaching.) While this paper does not formally compare and contrast results from the two studies (as the populations, instruction, and contexts were completely different), one can make a few tentative claims about how the nature of the population and the instructional context influenced the outcome.

Study I: Using model-centered science instruction with seventh-grade students

Context

The first study presented in this paper is one that I conducted at UC Berkeley within the ThinkerTools Scientific Inquiry project (White & Frederiksen, 1998). In that study, I created a 10.5 week model-oriented force and motion curriculum for seventh-grade students in an urban San Francisco Bay Area middle school. The curriculum was an extensively revised version of the ThinkerTools Scientific Inquiry Curriculum (White & Frederiksen, 1998) that was redesigned to embody a modeling approach (Schwarz, 1998; Schwarz & White, 2000). It is called the Model-Enhanced ThinkerTools curriculum, or METT.

There were three important components of METT that entailed a model-centered approach. Important components of the approach included (1) enabling the students to chose from alternative computer models of force and motion in order to embody and envision their conceptual models, (2) evaluating their models with criteria that characterize good scientific models, and (3) reading and reflecting on passages about models and modeling such as what a scientific model is, how the computer program works, and the utility of computer models. Students also watched and discussed a videotape that I created of modern uses of computer simulation models which included a segment of a computer simulated tornado storm, a simulation of two galaxies colliding, some impulse-based simulations of objects moving on surfaces, and a short clip of the video animation movie “Toy Story.”

The curriculum and instruction ran for approximately ten and a half weeks in eight classes in a school with a diverse population and a high proportion of low-income students. Of the eight classes, I co-taught one class with one teacher and was an aide for another teacher at the school.

In METT students studied force and motion topics including:
(1) one-dimensional motion with and without friction
(2) two-dimensional motion
(3) and students researched a project on their own about either gravity, mass, or gas/fluid resistance.

I now briefly describe how students engaged in this curriculum and instruction. Students conducted their research within a scientific inquiry cycle – a model of scientific inquiry that was made explicit throughout the curriculum. So for example, after either the introduction of the curriculum or after some prior research, the teachers and I might have begun a module asking students a question such as ‘How does gravity effect the speed of a falling object?’ Students then made alternative hypotheses about the answer to this question (such as: it causes objects to speed up, slow down, go at a constant speed or speed up until it reaches a constant speed.) Students also justified their response with a reason and shared these hypotheses with each other in class discussion. In the investigation phase of the inquiry cycle, we broke students into pairs (or sometimes larger groups) and conducted real-world experiments about the research question. For example, to investigate how gravity affects the motion of objects, they might have dropped objects from different heights and measured the time they took to fall to the ground.

In the analysis phase of the inquiry cycle, the students then analyzed their real-world data. In the modeling phase of this curriculum students then created a tentative rule to characterize what happened in their experiments. We then broke them into pairs and sent them to the computer to choose the model that most closely fit their rule. For example, if they had decided based on conducting their observations that gravity causes object to fall at a constant speed, they might have chosen the qualitative model “Constant Speed.” Alternatively, if their results suggested that the object sped up, they could have picked the non-Newtonian rule “Speeds Up. Gravity causes a falling object to speed up.” Once students completed this model creation step, they ran a simulation that used their model to see the ramifications of this model. Again, the main point of this modeling step was to see if the model they had created based on their data actually looked right. We also encouraged the students to compare their model to the Newtonian model design, which was never introduced as the “correct answer,” only that Newton was a famous physicist from the 17th century who created important models of force and motion. As mentioned before, students in the modeling phase of the inquiry cycle also worked in pairs to read and reflect on passages about the nature of models.

In the final phase of the inquiry cycle, students in METT evaluated their chosen model with four criteria that characterize good models used throughout the curriculum. These criteria included accuracy, plausible mechanism, utility and consistency. Students in the evaluation phase of the inquiry cycle also applied their model or law to other situations in the real world to see their utility as well as to evaluate their limitations. (So for example, what does your gravity model say should happen if you jump off tables from different heights? Will you land just as hard or harder from a higher height? Why do we hear about this thing called terminal velocity and what is it about?) Finally, METT students engaged in often lively debates to determine the best model according to real world data and evaluation criteria. The debates provided students with an authentic context or purpose for the modeling process by getting students to try understanding the various models, and it brought in their in prior knowledge and real world experiences.

Method

What did students learn from this experience? Was there any evidence that students' epistemologies of models was linked to their conceptual physics learning? Which activities played an important role in providing a rich epistemological context for students? For the purposes of this study, I'll discuss data from two written paper and pencil assessment (pre and post) about the nature of models and physics as well as an extensive interview with a subset of twenty three students several months after the curriculum and instruction ended, and my own journal entries and teacher logs. We note that extensive data was collected of multiple different forms (videotapes of almost all classes, student research books and projects, other types of written assessment related to scientific inquiry and the nature of science etc.) for this project, but these sources best address our primary research questions in this session.

We also acknowledge that paper and pencil pre- and post- tests are not a complete method for understanding student learning, nor do they give information about the causality of student learning. However, they can provide one important source of information that captures broad trends in thinking for large groups and can be easily used for looking at important factors (like gender, teacher, etc.) in the results. They can also be used to determine potential relationships among factors (through conducting correlations), and they can be more easily administered by teachers who want to analyze the impact of their own teaching. For these reasons, the paper and pencil tests were an important source in providing some information on the relationship between students' conceptual knowledge and their epistemologies of modeling.

The written modeling assessment included questions about the nature, evaluation and purpose of models in various question formats. Those formats included a sorting task (circling all types of items that are models), enhanced multiple-choice questions (e.g. "What is the best definition of a model and why?), and enhanced true/false questions (e.g. "Could a scientist create an incorrect model and why?"). The written Applied Physics test, used in the ThinkerTools Inquiry curriculum (White & Frederiksen, 1998), included sixteen enhanced multiple-choice items that assessed physics concepts ranging from knowledge about one-dimensional motion with and without friction, to two-dimensional motion and gravity. For example, in one sample item, students were asked "Imagine that a spaceship is coasting along in deep space. It is not near any planets or other outside forces. What will be true about the speed of the spaceship as it moves along? (a) the speed will decrease, (b) the speed will remain the same, or (c) the speed will increase. Explain the reasons for your choice."

The modeling interview included questions about the nature of models, the process of modeling, the evaluation of models, and the utility of models and modeling, and it lasted between thirty and fifty minutes. The interview included contextualized questions about models and modeling related to students' final projects ("Did you get a chance to try out the different rules for your research findings in the modeling step of the inquiry cycle? Why should a student do this?"), decontextualized questions about the nature of models and modeling ("In general, is any model just as good as another?" "Do scientists ever change or revise their models?"), and two activities, ("Here are two examples of scientific models of gravity. How would you decide which is the best model?" and "Suppose that you wanted to find out how long it takes for a student to get between classes at your school. Using the inquiry cycle, describe how you might investigate this question.")

We note that both the written modeling test and the modeling interview are primarily assessing students' articulated epistemologies of models. Again, this is far easier to assess both from a teacher's and a researcher's perspective, although perhaps somewhat less valid. We plan to further test the relationship between articulated and non-articulated epistemologies and students' conceptual knowledge gain in further studies.

Results

Analysis from both the written modeling test and the modeling interview indicates that students learned and retained a significant understanding of the nature of models, particularly abstract types of models. At the end of the curriculum, roughly half the seventh-grade students were able to identify a scientific theory, a causal rule, and an equation as a form of a model compared to less than a quarter at the beginning of the curriculum. Seventy-three percent of the interview students demonstrated a high level of sophistication about the nature of a model, indicating an abstract notion of a model as something that helps predict or explain, and is not necessarily visual or concrete. The most common response (55%) was that a model was a predictive or explanatory rule.

What did students understand about the evaluation of models? Analysis of the modeling assessment and the interview data indicates that students learned model-evaluation criteria and used those criteria in their own evaluations, but ended up claiming that all models had equal value stating things like, "all models are good when there is no way to know which one is right" or "because everyone has a different opinion." We believe this result was in part due to the social norms of the classroom and in part due to the fact that it was difficult to evaluate some of the physics models with the criteria. Many rule-based models seemed quite similar and quite reasonable (given students' intuitive conceptions), even if some of them were scientifically incorrect.

Students also learned a significant amount about the utility of models and modeling. For example, seventy-three percent of students in the interview thought the model-design aspect of the software in the curriculum was useful for visualizing and testing alternative models including their own, stating things like "[The model-design part of the software was there] to show you what you picked so you could see which one looked better and to make you think about which one was right." Since the correct physics was not prominently displayed in the computer model, students in this study learned the purpose of a model in science was to develop and test ideas.

What evidence did I find of a relationship between students' modeling epistemologies and their understanding of the physics content? I found that initial modeling knowledge (as determined by the written modeling pre-test) significantly correlated with the physics knowledge that students' acquired during the curriculum (as determined by the Applied Physics post-test) (.56), and that modeling knowledge students acquired during the curriculum correlated even more strongly with the physics knowledge students' acquired during the curriculum (.62). (As determined by results of the written modeling and physics assessments.) This result may indicate that modeling knowledge plays an important role in learning the physics.

In addition, what kind of instruction provided rich contexts for developing students' epistemologies of modeling? Going back to the original design of the intervention, it does appear that several aspects provided rich contexts for students although the design of the study was such that we were not able to separate the effects of these various instructional tasks. Important contexts as determined from journal entries and my own teacher logs included using well-designed dynamic computer simulation models that enabled students to envision and test theories, reflecting over the nature of models and the process of modeling both in the reading passages and in class discussion, and evaluating models according to criteria (particularly within the context of class debates which brought this issue to the forefront). There were additional aspects of this study that probably also fostered students' epistemologies such as engaging students in model-centered experiences over a significant period of time and thinking about how models can be found and used in our everyday lives (such as different representations of maps, or advertisements on TV, or movies.) Further, I suspect that seeing multiple types of models aided in giving students a better understanding of the overall nature of models and the process of modeling.

Study II: Using model-centered science instruction with pre-service elementary teachers

Context

In this second study, results come from studying my own undergraduate general science course at Brooklyn College, CUNY. My course included seventeen undergraduate students (primarily sophomores) who were in the process of obtaining their elementary teaching credential and their undergraduate degree in education. Most of these students were middle to lower income students, and most were roughly twenty-years old, although some were in their late twenties or early thirties. As is typical for an elementary teacher population, all students were female except one, and the students were ethnically diverse and representative of the larger population of Brooklyn, New York (Caucasian including Italian-American, African-American, Caribbean-American, and others). Most students in this course had taken one or two college-level science courses prior to my own.

General Science 10 was a required course for sophomores in elementary education at Brooklyn College, and this course was paired with a science methods course. The vision of the course was to engage elementary pre-service teachers in scientific inquiry and content exploration within two disciplines chosen by the instructor. I chose to pursue topics in astronomy and physics. The course met for 2.5 hours once a week for 14 weeks.

In the course, students engaged in a variety of science activities and investigations. Specifically, students investigated models and evidence about the shape of the earth, created a scale model of the solar system, observed the moon and created models of what causes the moon phases, collected and analyzed evidence for different hypotheses for the cause of the seasons, and conducted experiments about one-dimensional motion, and gravity. While engaged in studying the moon phases and the seasons, students used the software Starry Night^{TM}, an astronomical simulation of the sky that can allow an observer to see the sky from any position on the earth at any time and from several different perspectives. It also allows the viewer to quickly or slowly step through time to see what kinds of changes are occurring throughout the day and night. While engaged in studying one dimensional motion and gravity, students used the ThinkerTools software discussed in the first study. Students in this study did not use the ThinkerTools software for envisioning their theories (as they did in the first study), but in it's prior form -- as a microworld environment that allowed them to better understand and internalize Newtonian laws. Students also engaged in an inquiry project of their own choosing at the end of the course such as "Is there life on Mars?" or "How does mass affect the motion of a falling object?" Finally, in one entry of their science journals, students' read and reflected on a chapter of an elementary science methods book (Science Stories, Teachers and Children as Science Learners by J. Koch) on the use of models in science and in science education.

What did this instruction look like on a typical day? On a typical day, we might begin by spending twenty minutes discussing science articles in the New York Science Times, we might then conduct investigations related to the causes of the seasons such as (1) investigating how indirect sunlight (not quite perpendicular to the source) compares with direct sunlight (perpendicular to the source) in heating up a thermometer wrapped in black paper? (2) looking at how shadows caused by nails taped to a globe (exposed to a lamp representing a sun) might differ at various latitudes, or (3) looking at the sun's position in the sky (rising and setting location, and height of sun in the sky) at various times of year through the Starry Night^{TM} software. Later, we might analyze the evidence and categorize the evidence according to which hypothesis it supported. The students created two main hypotheses: (1) 'the seasons are caused by differences in the position of the sun in the sky,' and (2) 'the seasons are caused by the differences in distance between the earth and the sun because of the earth's tilt on its axis.' A typical day would also include two students in the class conducting short science lessons (approximately half an hour and not necessarily related to astronomy or physics) for their classmates.

To summarize, students created and used physical and written models in several different science contexts, they used two different types of computer simulation models, they evaluated their models with criteria (although this was less of a formal component compared to the seventh-grade curriculum), and they read and reflected on a passage about models in their journals and in our class discussion.

Method

This study was exploratory classroom research without a formal experimental design. In this study, I analyzed students' learning throughout the semester by studying their weekly journals and by analyzing their learning at the end of the semester as indicated by their performance on the final exam.

The written final exam included science content questions and questions related to students' understanding of models and the process of modeling. Several of the written questions were identical to those used in the seventh-grade study. These questions addressed three of the four different dimensions of modeling knowledge from the prior work including what students' understood of the nature of models, the modeling process, the utility of models, and the evaluation of models. These questions included:

> *Which of the following items do you think are models? (Choose all that apply) In a few sentences, explain why these items are models.*[Diagrams of different kinds of objects were presented to the students here.]
>
> *In general, is any scientific model as good as another? Why or why not? If not, how would you decide whether one model was better than another?*
>
> *How do you think computer models and scientific models can be useful? Explain 3 or 4 different ways.*

Methods and rubrics used to analyze these data were nearly identical to those used in the seventh-grade study.

Finally, student journals also gave evidence of students' understanding of models and the process of modeling. In particular, the modeling chapter from the elementary methods book prompted many students to examine the idea of models and their role in science education. While no formal analysis was conducted of the journal work, I was able to select some excerpts for illustration.

Results

What did these Brooklyn College pre-service elementary teachers learn about the nature of models and the process of modeling? Analysis of the written model assessment items on their final exam indicates that students had a strong understanding of the nature and purpose of models, and a particularly strong understanding of the evaluation of models. (There was not enough information to accurately assess their understanding of the process of modeling.)

These are typical responses to the items on the written exam:

<u>Nature of models:</u> "A model is a physical/concrete representation of concepts, ideas, theories and laws."

<u>Evaluation of models:</u> "All models are different. Some are better than others. To decide if a model is better than another, you must look at the model's accuracies and limitations. …"

<u>Utility of models:</u> "Models are useful in the physical sense (moon model, solar system model), computer models are useful when you want to expand on the scientific models like when we went to the lab to demonstrate the hypotheses we had in class."

How did this compare to the seventh-grader's knowledge? The Brooklyn College (BC) students had a roughly equivalent understanding of the nature of models compared to the seventh-graders. On one identical question, 59% of BC students had sophisticated responses[1] to the nature of models question compared to 48% of the seventh-grade students. In other words, both populations were good at identifying items that were models although the pre-service teachers were more focused on physical models, perhaps

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[1] While we acknowledge that determining exactly what is a sophisticated response depends on context, we also acknowledge that experts and novices generally have different responses to such items and experts are more likely to respond with richer, and more well-supported explanations.

because they were identified first through astronomy early in the course. They also did less well on identifying and thinking about abstract models such as equations.

The BC students had a significantly better understanding of the evaluation of models compared to the seventh-graders (in other words, thinking about whether some models are more accurate, better, etc. than others). On one identical question, 94% of BC students had sophisticated responses to the evaluation of models question compared to 33% of the seventh-grade students. Again, this result may be due to the nature of the type of activities engaged in the curriculum and the differences in computer model use.

Finally, the BC students had a roughly equivalent understanding of the utility of models compared to the seventh-graders (in other words, models be useful for science, learning etc.). On the identical question, 82% percent of both BC students and seventh-grade students had sophisticated responses about the nature of models. On the one hand, the seventh-grade students thought of models as useful for envisioning and testing their theories, and the other hand, the pre-service teachers thought of models as useful for visualizing the science for learning and teaching the science.

To further illustrate the BC students' thinking about models and modeling, I present an excerpt from a student journal reflecting on the nature of models in science learning and teaching. This journal entry is a response to reading the chapter on models from the Koch elementary methods text.

> Excellence in science education embodies the ideal that all students can achieve an understanding of science if they are given the opportunity and to me this opportunity applies to using models to emphasize a lesson. Learning science is an active process not something that is lectured to us always from a textbook. Different students achieve understanding in different ways and the use of models whether physical, mental or computer has certainly helped me broaden my understanding of whatever topic is taught in class. I am very grateful that we use models to help with our comprehension of astronomy. The first mini-lesson that was done in class by Carlotta and Angelica on the solar system reiterated for me what I did not fully understanding in our class. We used clay [to model the planets] with this mini lesson and of course it was not the exact version of the solar system, but it certainly represented what the solar system looked like. The [methods chapter] gave us an example of how a teacher used fruits in his lesson on the solar system, the students recognized that the model is much smaller than the real thing, the planets were not moving, the distances were much smaller and some planets have moons; but what was most important was that the students did a good job in evaluating their fruit and vegetable model. Since I am not a good student of science I need to work with concrete objects and I don't care what type of materials are used as long as I could visualize what I need to understand. Models are great because [they're common, inexpensive, they can be used in other subject areas and can contribute to collaboration.] … I am not saying that I understand every lesson that was taught using models for I am still struggling with the moon phases and the lunar and solar eclipse[s] but I will leave this class knowing much more than I knew before thanking the use of models for the additional help.

This journal excerpt illustrates how some of the GS10 Brooklyn College students, presumably motivated by wanting to understand the science they might be required to teach, understood a little bit about what models were, found scientific modeling interesting and useful, and that in turn may have motivated them to understand the content in greater depth.

As you can see, this undergraduate study did not lead to any formal results connecting students' epistemologies of models to their learning of science content. Nonetheless, because this class worked so heavily with various forms of models to understand the science content and because we used language about models in our classroom talk, it would be hard to imagine that students wouldn't have benefited from having a more sophisticated understanding of the role of models in science and science education. For example, one student group in teaching their mini lesson at the beginning of the semester asked students to create physical models of the planets using different kinds of clay. These students asked their fellow classmates at the end of the activity to discuss how the physical models they created were similar and dissimilar to the actual solar system. This idea of understanding the relationship between model and objects being modeled continually arose throughout the course where students remembered that models are not exact replicas of the physical object or phenomena. This in turn may have helped their conceptual understanding of science by enabling them to realize that they should not interpret and assimilate pictures, physical models, and diagrams of the solar system literally because these representations were models with some accuracies and some limitations. A little bit later, another student conducting her mini teaching activity asked students to decide whether an apple or an orange was a better model of the Earth. During the lesson, she came to me distressed that the other students had picked the wrong fruit! (The book had indicated that the apple was a better representation.) I told her that different objects could provide better representations for modeling some aspects than others, and that this was fine as long as the other students had a reasonable explanation for their choice. I think this experience may have helped her better understand the relationship between scientific information (data) and models (theory). (See her journal excerpt above for a continuation of her thinking about models.)

To address the second research question, several situations, including some of the ones mentioned above, seemed to provide rich contexts for developing students' epistemologies about models – or at least having students' potentially revise their epistemologies about models. Derived from analysis of student products (their journals, final projects, final exam), and observations of my own teaching and interaction with students, those situations included students (1) using and creating physical, conceptual, and computer models while observing their effectiveness for learning (particularly abstract) science content, (2) reflecting on the nature of modeling with respect to its role in science and in teaching science, (3) evaluating various theories and models for consistency with evidence (including data), and (4) addressing the utility of models in multiple different science and science teaching situations.

Discussion and Implications

To return to the main topic of this session, is there any evidence that epistemologies about models influences science content learning with models? This is an important issue if we want to advocate addressing epistemological issues in the classroom. I have provided some evidence from the first study in this paper that student's epistemologies of models was correlated with their physics performance indicating that epistemologies may play an important role in student learning. However, the design of the study did not enable me to determine how this interaction might have occurred. The second study did not provide confirmatory evidence for this connection, but did provide some potential mechanisms for how this interaction between epistemologies of models and content learning may occur – for example that a better understanding of what models represent may lead to a better understanding of how to interpret their information for conceptual understanding. Nonetheless, further studies are needed to determine the connection between epistemologies and conceptual knowledge and to elaborate on the mechanisms that may cause this to occur.

As far as developing principles for fostering productive epistemologies, these two studies suggested several contexts including using strong examples of dynamic computer simulation models, reflecting on models, evaluating models, and using/creating models in the context of areas important to students. We also note that results from these two studies indicate that different populations (with different interests and purposes) responded to somewhat similar contexts by developing different epistemologies of models. In other words, we found that students think about models differently when they are used for different purposes such as finding the correct scientific answer, or exploring one's own theories. This has important implications if we are to advocate particular contexts or approaches.

Future Directions

I plan to continue this avenue of research by teaching an undergraduate science course for pre-service elementary teachers at Michigan State University using a model-based inquiry approach. This model-based inquiry approach will incorporate many of the principles derived from these and other studies to provide an effective science course for fostering students understanding of science and their epistemologies of models. This study will involve careful analysis of language and videotapes of students creating and using models within the various instructional contexts to determine how those instructional contexts effect their learning. Throughout this future study, I will also aim to refine methods and assessments to determine students' epistemologies in the context of their actions and in their reflections. (both for research and teaching purposes).

My expectations is that this future study will contribute a better understanding of the forms of epistemologies, methods for how to assess them, further evidence that improving epistemologies influences science content learning, and an elaboration of principles for fostering productive epistemologies in learning with models.

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