Supporting Preservice Teachers’ Use of Modeling: Building a Water Purifier

by Young Ae Kim, University of Georgia; & J. Steve Oliver, University of Georgia

Abstract

Research has shown the value of modeling as an instructional practice. As such, instruction that includes modeling can be an authentic and effective means to illustrate scientific and engineering practices as well as a motivating force in science learning. Preservice science teachers need to learn how to incorporate modeling strategies in lessons on specific scientific topics to implement modeling practice effectively. In this article, we share an activity designed to model how the effectiveness and efficiency of a water purifier is impacted by creating a primary purification medium using different grain sizes and different amounts of activated charcoal. We seek for the preservice science teachers to learn how modeling is a process that requires revision in response to evidence. The water purifier activities in this paper were adapted for use in a secondary science teacher preparation program during the fall semesters of 2015 and 2016 as a means to introduce an effective modeling activity that is in the spirit of NGSS. These activities also support preservice teachers’ development of teacher knowledge relative to ‘model-based inquiry’ as well as teaching systems thinking. In addition, preservice science teachers learn how to think of modeling as an assessment tool through which they might gauge students’ understanding. Modeling may be used as a form of authentic assessment where student accomplishment is measured while in the act of constructing a model, revising a model or any of the other modeling related processes.

Introduction

Modeling is a core component of the scientific and engineering practices (SEP) in the Next Generation Science Standards (NGSS Lead States, 2013). The prominence of modeling practice within the NGSS is intended to reflect its importance to scientists as a tool to describe, explain, or predict scientific phenomena. As such, in school science instruction designed with NGSS in mind, students construct, revise, and evaluate models while learning inquiry skills as a component of scientific knowledge (Namdar & Shen, 2015). Modeling has been shown to be an authentic (Gilbert, 2004), effective method for classroom inquiry (Krajcik & Merritt, 2012), that is cyclic and dynamic (Lesh et al., 2000; Schwarz et al., 2009), and can serve as an active learning approach (NRC, 2012, Quellmalz et al., 2012).

“A representation that abstracts and simplifies a system by focusing on key features to explain and predict scientific phenomena” (p. 633) is the definition of a model provided by Schwarz et al. (2009). Prins et al. (2009) further specified the notion of a representation by labeling a model as a ‘structured representation’ of the essential characteristics of an idea, object, event, process or system. Further, models are used to describe, explain, predict, and communicate a referent (such as a natural phenomenon), an event or an entity, with others (Shen & Confrey, 2007).

Halloun (2007) linked models to science when defining models as the “principal means that scientists represent, investigate, control, and impose order on physical systems and phenomena, and put together scientific theory coherently and corroborate it efficiently” (p. 653). In this sense, models act as a bridge between scientific theory and experienced phenomena (Gilbert, 2004). Scientists explain objects, events, or systems, as well as, predict scientific phenomena through models. Models function in this manner by providing descriptions, simplifications, abstractions, visualizations, and idealizations (Gilbert, 2004) based on the analogous features between the model and what is being modeled. To understand a phenomenon, we often need accessible forms of explanations or multiple representations. In this paper, we broadly define modeling as a tool for creating representations of objects, events, structures, processes, or relationships to describe, explain, and predict natural phenomena or systems and for communication with others. Based on the literature, the term “modeling” reflects the definitions of inquiry provided by the National Science Education Standards (NRC, 1996) in that it is both a means for representing scientific ideas within instructional settings and also a tool for engaging students in scientific activities.

Modeling in Preservice Science Education

Preparing preservice science teachers to use modeling in classroom instruction is an area of teacher education scholarship in which considerable confusion exists (Kenyon et al., 2011). However, scholarship suggests that teacher preparation programs can support preservice teachers’ understanding of modeling practice (Windschitl & Thompson, 2006; Crawford & Cullin, 2004). Given the importance of the alignment with the NGSS (NGSS Lead States, 2013), preservice teachers need support to understand the role and implementation of modeling within curricular enactments of scientific and engineering practice. Research in science education has provided a variety of reasons why modeling has not been a major feature of school science. We briefly summarize that body of research within three factors that evince direct implications for preservice science teacher education. First, teachers, generally, do not have well developed knowledge of models and modeling (Justi and Gilbert, 2002; Kenyon et al., 2011). Second, the ways in which students can encounter modeling as a component of robust learning experiences are not well understood by teachers (van Driel and Verloop, 2002). Third, there are relatively few high-quality science curriculum materials that have been developed for the expressed purpose of supporting student learning through modeling (Kenyon et al., 2011). Thus, well-designed modeling experiences in teacher preparation programs are needed to support preservice teachers’ development of teacher knowledge about models and modeling.

Kuhn (2005) asserted the importance of meta-level understanding as a means to apprehend critical thinking. She emphasized meta-strategic understanding. This form of meta-level knowing fashions insight into awareness of why some strategies can be more or less effective than others. We believe that our approach, as described in this article, supports the development of this kind of meta-level understanding of modeling practice and is critical in order for preservice teachers to enact modeling practice in their future science classrooms. Consider the following example. We assert that preservice science teachers need to learn how to incorporate modeling strategies in lessons on specific scientific topics. Our strategy for supporting this learning is to have the preservice teachers dissect their experiences during in-class modeling activities with emphasis on development of their strategic knowledge. By having the preservice teachers describe (in written form) how aspects of their own experiences can be transformed into instructional strategies, we believe that they not only learn about implementing instructional modeling practices effectively, but also are primed for the acquisition of meta-strategic understanding as their experience with modeling grows.

Specifically, in this article, we share an activity designed to model how the effectiveness and efficiency of a water purifier is impacted by changing grain sizes of the primary purification medium, activated charcoal. We sought for the preservice science teachers to learn how modeling is a process that requires revision in response to evidence. We have adopted Schwarz et al. (2009) schema for an instructional modeling sequence which has the following steps: 1) Identifying anchoring phenomena; 2) Constructing a model; 3) Testing and Evaluating the model; 4) Revising the model; and 5) Applying the model to predict or explain other phenomena. This instructional modeling sequence has been demonstrated to support teachers as they guide students into effective engagement with modeling activities; we employ it as a heuristic tool and referent for the preservice science teachers.

The water purifier activities in this paper were first used in the first author's middle school science classroom. The activities reported here conducted within classes of a secondary science teacher preparation program during 2015 and 2016. These classes are the final formal classes prior to student teaching. The preservice teachers who conducted the activities were about 60 percent undergraduates (BSED in Science Education) and 40 percent graduate students (MAT). Few of the participants had prior teaching experience at any level, but were involved in a school-based practicum at the time of these activities. In the specific context where this material was used in teacher education, these activities use iterative model construction and revisions to illustrate whole class collaboration in an integrated STEM context. Thus the preservice teachers accomplished an application in engineering design while creating the optimized water purifier.

Finally, we designed the activity so that preservice teachers would be scaffolded toward thinking of modeling as an assessment tool. Specifically, we planned for the preservice teachers to become aware of how they might gauge students' understanding that emerges while in the act of conducting a modeling process. We found that many preservice teachers were able to recognize instructional paths through which they might assess how students understand scientific ideas as a result of model constructions and model revisions. Further, we believe that when the preservice teachers recognize how modeling can also serve as an assessment, new avenues are opened for thinking about assessment of student learning.

Context of Our Work

Water purification as a science classroom topic is highly relevant to the everyday lives of students, especially given the focus on drinking water in today's news media. Designing a water purifier is an excellent activity for the middle grades and higher levels to promote student thinking about systems. In particular, we focus on creating water purification systems that allow water to be filtered by particles of activated charcoal. This type of system is commonly used for water purification in aquaria and drinking. It is well known that activated charcoal removes chemical impurities from water through a process known as chemical adsorption (Lemley, Wagenet, and Kneen, 1995). The activated charcoal is a form of carbon with special characteristics that allow it to adsorb certain impurities that are attracted and bound to the surface of the adsorbing material. If the teacher chooses to do so, a variety of additional consumable materials, such as cotton, pebbles, sand, etc., can be used as components of the system design thus increasing the number of variables available to the students for examining what constitutes a significant contributor to a water purification device.

In our teacher education classes, we have adapted the activity to be more focused on a single filter media, activated charcoal, rather than using a variety of materials. This approach will place the focus on the characteristics of the activated charcoal. Using that singular media material supports our emphasis on examining the relationship among particle size, surface area, and resulting flow rates of water through the purification system. The intersection of these variables within the inquiry-based modeling creates a prime opportunity for preservice science teachers to practice systems thinking and system models, but also to think about future instructional uses of these practices.

It is important for preservice science teachers to participate in activities through which they learn introspectively how students could represent their ideas in order to explain what they observed in natural phenomena or designed systems (Kenyon et al., 2011). We believe that this activity also provides insight for those preservice teachers into the ways in which scientific and engineering practices are employed by professionals in the field.

Activity to Build a Water Purifier with Activated Charcoal

To initiate the activity, the preservice teachers are provided with a narrative scenario of a freshwater stream that is being polluted by a number of possible sources. The urgency of the situation is provided by the need to purify the water to preserve the life of fish found in that stream. The preservice science teachers are encouraged to think about how their science students could be introduced to this activity. Further, we asked the preservice teachers to imagine their science students' assumptions related to these investigations and reminded preservice teachers that before the activity, students might need to be guided back to their previous learning about particle sizes, surface area, and adsorption. Table 1 shows the Creating a Water Purifier Activity instructional sequence within a secondary science instructional methods course.

Table 1 (Click on image to enlarge)

Creating a Water Purifier Activity Instructional Sequence

• Provide pre-service teachers with a narrative scenario illustrating possible sources of pollution in a fresh water stream. (Urgency created by a need to save the life of a fish.) • Direct pre-service teachers to background information on natural processes of water purification including processes using activated charcoal. • Consider future students' assumptions and conceptions about the experiment.
• Introduce lab activity emphasizing the role of surface area and grain size. 1) Divide the class into laboratory working groups 2) Grind the activated charcoal to different grain sizes. 3) Discuss research design (independent, dependent, and control variables).
• Create an initial paper and pencil model *(Initial model)* • Decide how to build and then build the working model based on this "blueprint." • Collect data using the working model. • Conduct additional trials with the working model using different amounts of charcoal.
• Revise the initial model *(Revision 1)* based on collected data. (Refer to *Figure 2. Water clarification lab chart*).
• Generate questions about the use of activated charcoal in water purification based on evidence gathered across the entire class. Consider, what other factors could also influence the water purification?
• Search online resources about the activated charcoal, also examine the prepared samples of activated charcoal with microscope. (data collection) • Revising the models *(Revision 2)* based on new information. • Create a consensus model through class discussion.

After directing the preservice teachers to form their laboratory working groups and a brief review of research design (i.e., independent and dependent variables, as well as treatment and control groups), we begin the hands-on activities in the lesson. First, we model good science laboratory instruction by directing the preservice teachers to wear safety goggles when grinding the activated charcoal. Leading the grinding of the particles to particular grain sizes is the primary teacher-directed component of the activity. We have chosen this approach because of prior experience with the creation of water purifiers with actual school students. We also learned from this experience, for instance, that fine charcoal dust can pass through certain thin filter papers and so recommend use of only thicker filter paper in the water purifiers. The work begins with grinding the activated charcoal into three different grain sizes with mortars. Samples are available for the preservice teachers to use in grinding to a comparable consistency. These particles are used to create systems that are otherwise entirely of the student's design and through which a comparison can be made of the degree of water clarification achieved relative to the grain sizes of the charcoal.

Activated charcoal adsorbs impurities from water by first attracting these impurities to its surface and then binding them. The process of grinding (and its subsequent reduction in particle size) results in a complementary increase in total surface area for a given weight of charcoal. Thus, the smaller the size of the charcoal grains, the greater the total surface area among a given weight of charcoal available for adsorption (See figure 1). Smaller particle size also affects the variable of flow rate with the smallest size of charcoal grains having the slowest flow. In a similar manner, increasing the amount of charcoal (regardless of the grain size) increases the total surface area available for adsorption and, therefore, also improves the clarifying capacity of the purification system.

Figure 1 (Click on image to enlarge). Water clarification lab chart.

Students conduct an experiment on filtration flow rate according to the size of charcoal grains and the degree of water purification according to the amount of charcoal grains. The following table is the setting that my students discussed and conducted. Across the class, students will experiment with different grain sizes in Experiment 1, and with different quantities in Experiment 2.

Experiment 1

Size of charcoal grain	Small (powder: <0.2cm)	Medium (0.3 ~0.6 cm)	Large (>0.7cm)	Control variable : Amount of grains (50g) and dirty water (100ml) must be same at three different tube.
Flow rate (purification time)				
Degree of purification				

Experiment 2

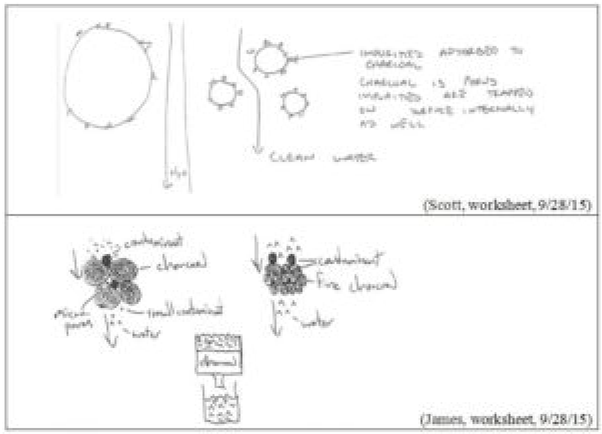
Amount of charcoal grain	30g	60g	90g	Control variable : Size of grains and amount of water must be same at three different tube.
Filtration time				
Degree of purification				

As the activity begins, we do not discuss the characteristics of activated charcoal in detail, because we want the preservice teachers to gain insight into the changing nature of models by inquiry and the building of a model. We see the impact of this inquiry learning when they revise the model based on evidence and knowledge accumulated during the first trial.

First, a sample data chart was created for the central accumulation of data (See Figure 1). The size of the charcoal grains as an independent variable and the degree of purification and water flow rate as dependent variables were suggested by the preservice teachers. They also hypothesized how the degree of water purification and water flow rates would be measured and recorded in each water clarification system.

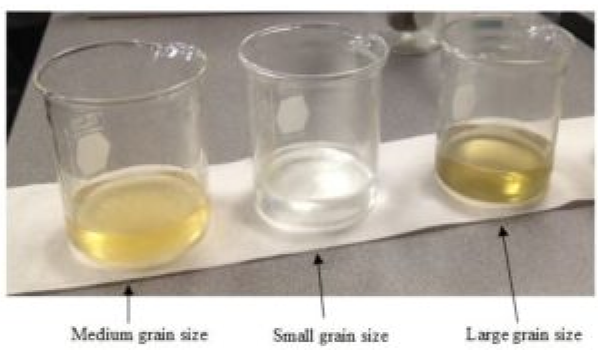
The next step involved the creation of a paper/pencil drawing of an initial model design (See Figure 2). This was done individually, but soon afterwards, was considered collectively among the working group. With the visual model in hand, the preservice teachers were able to list and describe variables that might be tested, such as water clarity (serving as a proxy for purification) and water flow rate, through the model. Then the preservice teachers built their working model and used it to collect data.

Figure 2 (Click on image to enlarge). Examples of initial models.



Representatives from each working group also compared each purification system throughout the class. This comparison showed that the water purifier with the smallest grain sizes produced the clearest water (See Figure 3). Upon completion of the testing of the working models, the preservice teachers were asked to consider if their initial predictions were supported or rejected by the evidence (i.e. the analysis of their collected data). Then, preservice teachers were given the opportunity to revise and rebuild their models. Because of time limitations, subsequent revisions to the models were to the paper and pencil models only. However, it would be reasonable to have the preservice teachers make multiple working models if time permits.

Figure 3 (Click on image to enlarge). Purified water from experiment 1 groups.



Some preservice teachers chose to revise their models, but most preservice teachers thought their initial beliefs about the model's design were supported by the data. In one class, two groups of preservice teachers shared their initial and revised models as well as the reasons for their revisions with the class. Their reasons supported our objective that the preservice teachers needed to learn that a model can always be tested and revised. As a class, the preservice teachers discussed the process in which they created, revised, and refined their own models as learning experiences to engage students in modeling practice.

After the first investigation (the lab experiment), the preservice teachers were instructed to think of new questions about the design and use of water purifiers based on their models. As was stated earlier, the initial designs were mostly focused on the grain size and amount of activated charcoal. In an effort to encourage preservice teachers to probe their understanding more deeply about activated charcoal, as well as a means to promote metacognitive thinking, the instructor asked the questions, “If you use sand to clarify water instead of charcoal, will sand have the same effect?” and “What is the meaning of the term “activated” in activated charcoal?” To the first question, the preservice teachers immediately recognized that their answer would depend on the structure and the properties of the activated charcoal. So, they again investigated the activated charcoal using online resources and examined the activated charcoal grains using a few prepared samples and microscopes. Then, they revised their models and created a consensus model based on additional data and discussions. In this interlude prior to the second investigation, the preservice teachers found that the activated charcoals have pore structures, and some of them have positive charged binding sites as a result of the activation process. (They also learned that there are many activation methods/processes.) So, they generated a prediction that the negative-charged impurities would have greater bonding affinity with activated charcoal. Also, they learned that impurities do not just get trapped, but they interact with the charcoal grains. Based on this new evidence, the preservice teachers modified their initial models or the first revisions of their models. Figure 4 and 5 show the examples of preservice teachers’ model revisions.

Figure 4 (Click on image to enlarge). Example of preservice teacher’s models (Debby).

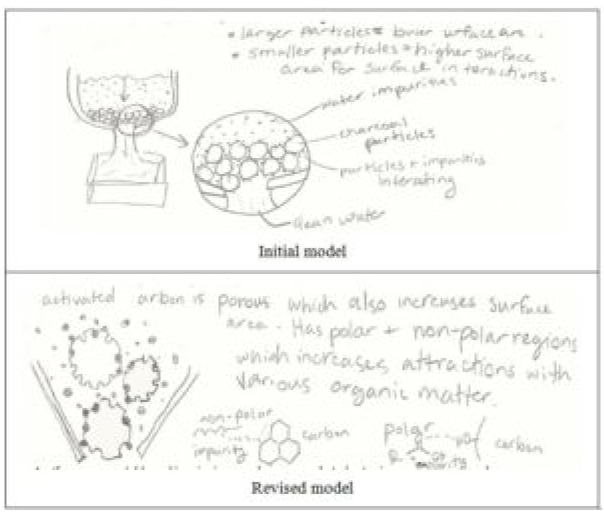
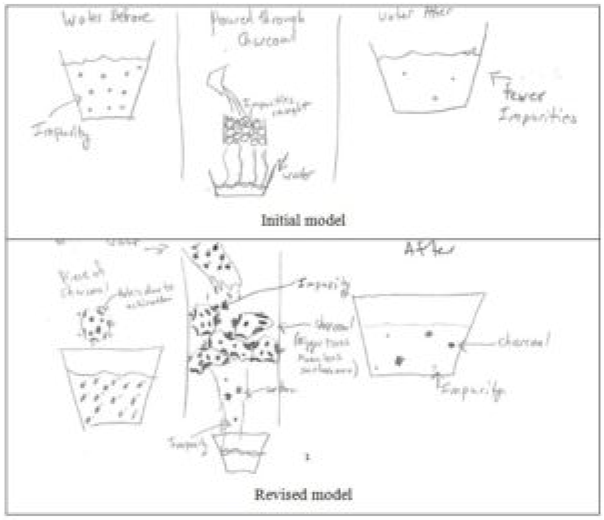


Figure 5 (Click on image to enlarge). Example of preservice teacher’s models (Jaden).



After the modeling activity, the preservice teachers discussed what they learned about models and modeling. Guiding questions for the discussion were: 1) What have you learned about scientific and engineering practices related to the modeling process (e.g., construction, revision, refinement, evaluation, presentation, etc.) based on today's modeling experience?; 2) What factors influenced your ability to make accurate predictions before and after the modeling activity?; 3) How can the knowledge, particularly with regard to the role of surface area and grain sizes, learned from this activity be applied to other contexts? (e.g., coffee making with grinding, Kidney's filtration); and 4) How would you modify this activity for future instructional use in your own teaching?

Preservice Teachers' Responses

As Russell and Martin (2014) and others have noted, teachers teach students in the ways in which they learned. But it is also often true that preservice teachers are resistant to new learning in teacher preparation programs (Russell & Martin, 2014). On the other hand, this also means that preservice teachers need to learn through experience before becoming in-service teachers. In our methods and curriculum courses, we intended to situate preservice teachers in a learning experience with modeling, which was a relatively unfamiliar area to them (Kenyon et al., 2011). Next, we will share some aspects of what we've learned from the preservice teachers' learning experiences with the activated charcoal modeling activity.

When we asked preservice teachers to draw initial models, their models were based on prior knowledge and experiences. The preservice teachers used modeling to explain and predict how the water is clarified with different grain sizes and different amounts of activated charcoal and how the water flow rate is affected by them. In the first step, preservice teachers were asked to focus on the structure and grain sizes of the activated charcoal, then subsequently on the interaction between the activated charcoal grains and impurities in the water for modeling the purification system. In their illustrated models, many preservice teachers created round-shaped charcoal grains of many different sizes or just drew one-size of circular charcoal grains in a water purifier with written descriptions. In general, the preservice teachers created models containing the objects: the water purifier, the charcoal grains, water, etc. Some models were simple but some groups created more abstract versions representing the process of building the water purifier like an algorithm (e.g., a step-wise process for construction). The models illustrated with circular grains might have reflected the instructor not drawing attention to the structure of activated charcoal grains at the beginning, and the preservice teachers' focus was on the grain sizes instead. However, a few preservice teachers, based on their prior knowledge, created irregular-shaped activated charcoal grains, more in keeping with the microscopic images of activated charcoal. In the water purification system model, some preservice teachers drew ancillary illustrations that "zoomed-in" and showed the interaction between the charcoal particles and the impurities in the water. In many cases, the preservice teachers didn't think about the structure of the activated charcoal grains and were not concerned about the influence of the structure to its functions in their initial models. Rather, they focused on the grain sizes or simple interactions (e.g., the impurities trapped) between the activated charcoal grains and impurities in the water, resulting in different degrees of water purification.

Preservice Teachers' Learning Through Hands-on Lab Activity

The preservice teachers were able to compare their predictions and their collected data. As many preservice teachers predicted in their initial models, the water purifier containing the finer grain sizes clarified the water better. And yet, the preservice teachers were generally surprised by the magnitude of the difference as shown in the experiment results. Throughout the lab experiment, the preservice teachers discovered many important aspects of the model design that were not predicted. One particular result pointed to the dynamic nature of the models. Some of the preservice teachers noticed that the water flow rate changed over time from the beginning of the clarification to the end. This led them to suggest a more explicit data table including a time frame measuring the water flow rate every two minutes. Then, a preservice teacher included this changing water flow rate in her written description when she modified the initial model. This finding is not one that they could have envisioned without the hands-on inquiry-based lab experiences. This also points to the scientific authenticity of the activity. And additional variables were also linked to the science in the activity. One of the preservice teachers conceptualized the role of pressure as a factor in the water filter. After this realization it became clear to others that pressure was definitely a variable that affected the water flow rate.

Transference of Learning to New Contexts

One of the main roles of a model is to predict or explain phenomena. Students develop predictions about how this principle (relationship) of surface area and grain sizes would function in a new context. At the end of the activity, the instructor introduced preservice teachers to 'coffee-making' by grinding coffee beans. The instructor asked, "How can you make strong coffee?" Each group discussed making strong or weak coffee by using their knowledge about the sizes and the amount of grains. In this case, their knowledge on the flow rate, the size of the charcoal grains, the amount of charcoal grains, and the degree of purification was transferred to coffee grinding/making. Just as the adsorption is related to grain size and quantity of charcoal grains, the smaller the size of the coffee grounds as well as the use of larger quantity means that more solute can be extracted. Extraction and adsorption are essentially opposite actions.

The preservice teachers also discussed where to apply the role of the surface area with different grain sizes in biological phenomena, such as function of the kidneys. A kidney filters blood. The instructor asked, “How is clarification different from filtration?” Filtration enters the discussion as an additional third scientific term and introduces another distinctive action. Filtration in the glomerular capsule is not adsorption but rather bulk flow screening based on the size of pores between cells.

Connection to Other Practices

The preservice teachers realized that water purifier models helped to illuminate understanding about the structure of activated carbon while creating a venue to explore scientific and engineering practices. One of the preservice teachers, Sunny, expressed it in this way, “modeling practice is connected to other scientific practices, such as planning and carrying out investigations, by collecting data from models and modifying models to collect more data.” (Sunny, Worksheet, 09/28/15). The preservice teachers started to recognize that inquiry starts with questions, and scientific ideas were expressed during the modeling process through predictions and explanations. Variables were managed and controlled in the investigation, and new questions based on the collected data were contemplated to construct modified models.

Connections between Scientific Concepts and Modeling Practice

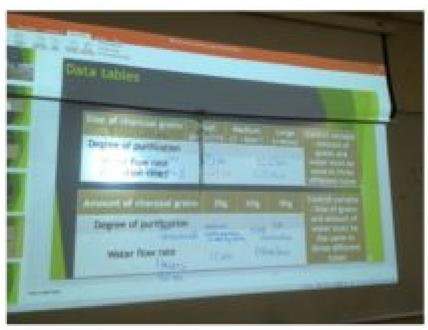
In general, after all the activity steps were finished, the preservice teachers indicated that the inquiry-based method was a great tool for building their own models and understanding of the modeling process. They also mentioned the benefits of modeling for teaching scientific ideas and concepts across a range of topics. Value was seen as a result of being able to visualize abstract concepts and to explain large/small scale concepts/processes that are otherwise hard to conceptualize. With regard to instruction related to this activity, the preservice teachers suggested a variety of practical ideas: assigning groups and passing out job cards to each group member (for middle school students), providing additional directions, constructing an explicit data chart with changing water flow rates, preparing a color key to determine the degree of water purification, etc.

In addition, the preservice teachers used their initial and modified models to engage in critical thinking and reasoning as an aspect of building new knowledge through experiences in active learning. They recognized the importance of model revision as a means to increase knowledge and the use of model revision within their future science teaching. Perhaps most importantly, the preservice teachers realized how the modeling cycle was an important aspect of the learning process: model construction – test – revision – evaluation (Schwarz et al., 2009). Thus, the preservice teachers recognized modeling's viability as a form of assessment of student learning.

Collaboration as an Aspect of Authentic Practice

The preservice teachers expressed appreciation for collaboration with regard to the role of accumulated data from the whole class, and also revision and generation of a consensus model. This collaborative approach is not only beneficial for student learning in science classrooms but also representative of authentic practice in scientific communities. Figure 6, along with the written description, is from Sunny's photo-journal and shows the data table from the whole class. Sunny expressed this representative comment in an interview, "Creating a class-wide model, assigning each group a different variable, really took advantage of the time and gave the class…like, at the end, we were able to come together and teach each other something about the model, which I really like about that actually" (Sunny, 12/01/15, interview). Figure 6 shows the data table on the screen and the description of the photo from Sunny's photo-journal. [Note: All interview comments reported in this article were collected under approval granted by university Human Subjects Office.]

Figure 6 (Click on image to enlarge). Data table from Sunny's photo-journal.



This is the class data table that was collected from the activated charcoal experiment. During this experiment, each group used the same kind of filtration set up. The manipulated variables were the size of the charcoal grains and the amount of charcoal grains. We concluded that the smallest grains (charcoal powder) produced the clearest water, and we determined that higher amounts of charcoal grains produced the clearest water. From this experiment, we learned about the properties of activated charcoal and were able to develop explanations about how the structure of activated charcoal is directly related to its function as a water purifying substance (Sunny, photo-journal, 12/1/15).

Conclusion and Implications

It is important for teachers to have a comprehensive view of instructional modeling practices, such as the quality of model planning, construction, revision, or evaluation. These processes engage learners in scientific practices and also create a means for learning scientific concepts actively and meaningfully. Better understanding of the mechanisms of modeling support teachers to constructively guide students to meaningful learning. This guiding process must include insight into: how students draw appropriate analogies between their models and targets; how they integrate interdisciplinary knowledge; how they use models as knowledge-building tools; and how creativity is involved in the modeling process. Therefore, it is significant for preservice teachers to understand what difficulties experienced including how students engage in modeling practices, how to elicit students' modeling skills and creativity during modeling, and how to help students recognize a good model is from among multiple examples.

The use of the instructional modeling sequence: construct, test, revise, and evaluate (Schwarz et al., 2009) in conjunction with the investigations described here enabled preservice teachers to go through the modeling process just as scientists do. In addition, system models and systems thinking, which require students to understand the relationships between and interactions of various components within and outside the systems, provide students with a robust knowledge base of scientific and engineering practices. Supporting preservice teachers in this manner is a powerful initiation to science teaching as it is to be conducted in conjunction with NGSS. From this introduction, preservice teachers can move forward toward conducting well-designed modeling-based instruction in a variety of topics.

References

Crawford, B., & Cullin, M. (2004). Supporting prospective teachers' conceptions of modeling in science. International Journal of Science Education, 26, 1379–1401.

Gilbert, J. K. (2004). Models and Modelling: Routes to more authentic science education. International Journal of Science and Mathematics Education, 2(2), 115-130.

Halloun, I. (2007). Mediated Modeling in Science Education. Science & Education. 16(7), 653-697.

Justi, R. & Gilbert, J. (2002). Modelling, teachers' views on the nature of modelling, and implications for the education of modellers. International Journal of Science Education. 24(4). 369–387.

Kenyon, L., Davis, E., & Hug, B. (2011). Design Approaches to Support Preservice Teachers in Scientific Modeling. Journal of Science Teacher Education, 22, 1-21.

Krajcik, J., & Merritt, J. (2012). Engaging Students in Scientific Practices: What does constructing and revising models look like in the science classroom? Understanding A Framework for K-12 Science Education. Science Scope, 35(7), 6-10.

Kuhn, D. (2005). Education for Thinking. Cambridge, MA: Harvard University Press.

Lemley, A., Wagenet, L., & Kneen, B. (1995). Activated Carbon Treatment of Drinking Water. In Water Treatment Notes Cornell Cooperative Extension. Retrieved from http://waterquality.cce.cornell.edu/publications/CCEWQ-03-ActivatedCarbonWtrTrt.pdf

Lesh, R., Hoover, M., Hole, B., Kelly, A., Post, T., (2000) Principles for Developing Thought-Revealing Activities for Students and Teachers. In A. Kelly, R. Lesh (Eds.), Research Design in Mathematics and Science Education. (pp. 591-646). Lawrence Erlbaum Associates, Mahwah, New Jersey.

Namdar, B. & Shen, J. (2015). Modeling-Oriented Assessment in K-12 Science Education: A synthesis of research from 1980 to 2013 and new directions, International Journal of Science Education. DOI: 10.1080/09500693.2015.1012185

NGSS Lead States. (2013). Next Generation Science Standards: For states, by states. Washington, DC: National Academies Press.

National Research Council (1996). The National Science Education Standards. Washington, DC: The National Academies Press.

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Committee on conceptual framework for the New K-12 science education standards. Committee on a conceptual framework for New K-12 science Ed. Washington, DC: The National Academies Press.

Prins, G. T., Bulte, A. M. W., Driel, J. H., & Pilot, A. (2009). Students' Involvement in Authentic Modelling Practices as Contexts in Chemistry Education. Research in Science Education, 39(5), 681–700. doi:10.1007/s11165-008-9099-4

Quellmalz, E. S., Timms, M. J., Silberglitt, M. D., & Buckley, B. C. (2012). Science assessments for all: Integrating science simulations into balanced state science assessment systems. Journal of Research in Science Teaching, 49(3), 363–393. doi:10.1002/tea.21005

Russell, T. & Martin, A. K. (2014). Learning to Teach Science. In Lederman, N. G. & Abell, S. K. (Eds.), Handbook of Research on Science Education, Volume 2. New York and London: Routledge.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Ache´r, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. Journal of Research in Science Teaching, 46(6), 632–654.

Shen, J. (2006). Teaching strategies and conceptual change in a professional development program for science teachers of K-8 (Unpublished doctoral dissertation). Washington University, St. Louis.

Shen, J., & Confrey, J. (2007). From conceptual change to transformative modeling: A case study of an elementary teacher in learning astronomy. Science Education. 91(6), 948–966. doi:10.1002/sce.20224

Van Driel, JH. & Verloop, N. (2002). Experienced teachers' knowledge of teaching and learning of models and modelling in science education. International Journal of Science Education. 24(12). 1255-1272.

Windschitl, M. & Thompson, J. (2006) Transcending simple forms of school science investigations: Can preservice instruction foster teachers' understandings of model-based inquiry. American Educational Research Journal, 43(4), 783-835.