Learning and teaching about scientific models with a computer-modeling tool

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Abstract

The study presents efforts to support pre-service primary school teachers in learning and teaching about scientific models, and discusses the impact of these efforts on their understandings. We provided pre-service primary school teachers with a module on computer modeling and studied the effects of this experience on their abilities to construct viable scientific models with a computer-modeling tool, namely, Model-It [Metcalf, J. S., Krajcik, J., & Soloway, E. (2000). MODEL-IT: A Design Retrospective. In M. J. Jacobson & R. B. Kozma (Eds.), Innovations in Science and Mathematics Education (pp. 77–115). Mahwah, NJ: Lawrence Erlbaum Associates], in order to teach a sixth-grade science lesson. The results of the study showed that Model-It, through its scaffolds (i.e., Plan, Build, and Test), enabled the majority of pre-service teachers to build models that were structurally correct, but simplistic. The participants showed a tendency to teach science using more often the explorative modeling method than the expressive method, and only few of them employed both methods in their lessons. In essence, Model-It effectively scaffolded pre-service teachers’ first modeling experiences and enabled them to quickly build and test their models as well as reflect on the viability of their models. However, according to the results, teachers need extensive learning experiences in order to achieve a comprehensive understanding of the process of scientific modeling in science.

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1. Introduction

Models and the process of modeling constitute focal aspects of science, but the role of models and modeling in science is usually a neglected aspect of scientific inquiry and the nature of science. Models are integral to thinking and working in science and constitute “science’s products, methods and its major learning and teaching tools” (Gilbert, 1993, p. 10). A model of an object or a phenomenon is a simplified imitation that, hopefully, helps our understanding (American Association for the Advancement of Science, 1993a). Models are constructed when an object or a phenomenon is too small, too large, too complex or too distant, in both time and space, or when the object or phenomenon is otherwise inaccessible. Models constitute important tools that enable scientists to generate predictions, as well as guide explanations, interpretation, understanding, and discovery in science (Jungck & Calley, 1985). Modeling tools provide scientists with new ways of creating theories, testing ideas, and analyzing data. Scientists make observations, identify patterns in data, and then develop and test explanations of these data using scientific models. Certain aspects of the nature of science that are directly related to the use of models are tentativeness and the need for continual revision and evaluation. Models and modeling activities in science should include and cultivate the tentativeness of models, the role that creativity plays in building models, the iterative aspect of modeling, and the fact that scientists can have more than one model representing the same phenomenon or object.

The National Science Education Standards (National Research Council, 1996) require science teachers to be knowledgeable in many aspects of scientific inquiry and the nature of science, including the role of models and modeling. The standards also call for science educators to focus on model-centered instruction by integrating appropriate technology in science teaching for the purpose of engaging students in inquiry and in a process of constructing knowledge.

Model creation and model-based reasoning represent core components of both human cognition and scientific inquiry. All students should develop an understanding of the nature of science including the knowledge that scientists formulate and test explanations of the nature of science using, among other things, theoretical and mathematical models. Students’ involvement in the process of creating, testing, revising, and using scientific models can help them make their thinking visible and test aspects of their conceptual frameworks. Student inquiries should culminate in formulating an explanation or constructing a model. In the process of answering questions, students should engage in discussions and argumentation that can possibly result in revision of their explanations (National Research Council, 1996, p. 175).

Models can be physical, conceptual, and mathematical, while computer modeling can also make scientific material more accessible and interesting. For example, computer microworlds offer students access to worlds that cannot directly experience, and create a sense of owning and directing the dynamics of these worlds (diSessa, 1985; Papert, 1980). Computer models can also facilitate the processing of complex data, make the scientific process more dynamic, and provide ways for studying interesting and complex phenomena. Additionally, many computer tools, such as MARS, Model-It, STELLA, and ThinkerTools (Metcalf, Krajcik, & Soloway, 2000; Raghavan & Glaser, 1995; Raghavan, Sartoris, & Glaser, 1998; Stratford, 1997; White, 1993), when appropriately used, can promote subject matter understanding, inquiry skills, and systems thinking (Richmond, 2001). A model-based approach can also promote the development of accurate and productive
epistemologies of science that in turn will help students to improve their reasoning using scientific evidence as well as better integrate their conceptual knowledge (Gilbert, 1991; Songer & Linn, 1991).

Nevertheless, teachers’ preparation in science often focuses primarily on the acquisition of facts and information, and conveys an image of scientific inquiry that is not aligned with the real nature of science or the scientific practice (Anderson & Mitchener, 1994). Many teachers also view models as representations of real-world objects or events, and not as representations of ideas about real-world objects or events. Furthermore, they do not possess adequate knowledge and skills related to building models for supporting students in learning science, learning about science, and learning how to do science (Justi & Gilbert, 2002). Besides, many science textbooks, including those that present scientific models, fail to identify them as such, and what are usually termed “science process skills” are experienced through “cookbook” or verification-type laboratory activities (Harrison, 2001).

Teachers’ pre-service and in-service preparation should involve teachers in inquiry learning and experiential learning as advocated by reforms in science education (Loucks-Horsley, Hewson, Love, & Stiles, 1998). Penner (2000/2001) argues that one method that could possibly assist the inquiry learning process is computer modeling. Modeling usually involves investigating real-world phenomena, as well as designing, building, and testing computer models related to a real-world investigation. Such modeling tools differ on a variety of dimensions, including the extent to which they focus on problem solving or theory development, and whether they engage students in exploring pre-made models or designing their own models. According to Bliss (1994), there are two types of modeling, namely, explorative modeling and expressive modeling. In explorative modeling, learners are asked to explore ready-made models that represent somebody else’s conceptions, they try out a model, look at cause and effect relationships, and draw conclusions based on the results of their exploration. They can also modify the model if there is a need to do so. In expressive modeling, learners express their own ideas and make a model or an external representation of their ideas. Subsequently, they can use their models to test hypotheses and based on the results of their investigations, they can revise their models for the purpose of improving them.

Despite the ongoing interest in models and modeling in science teaching and learning, there is only limited information regarding in-service and pre-service teachers’ knowledge about models and modeling in science. De Jong and Van Driel (2001) stated that pre-service teachers lack knowledge about the use of models in science, and that there is a pressing need to engage all prospective teachers in rich modeling activities, so that they become able to use models in science teaching and learning. Smit and Finegold (1995) reported that prospective science teachers had a view of scientific models as merely a representation used by someone who understands a phenomenon to explain it to someone who does not. Van Driel and Verloop (1999) also reported that even experienced science teachers failed to acknowledge how models are used in making predictions, or how models are used as tools for obtaining information about a target that is inaccessible for direct information.

Furthermore, only few studies attempted to measure and/or describe changes resulting from some form of intervention. De Jong and Van Driel (2001) investigated the development of prospective science teachers’ content knowledge and pedagogical content knowledge in the domain of models and modeling in the context of a postgraduate teacher education program. Surprisingly, their findings indicated that these prospective science
teachers, who held Masters of Science degrees in chemistry, did not have pronounced knowledge about models and modeling, and that some of the important functions of models, such as making and testing predictions, were rarely mentioned by them. Crawford and Cullin (2004) also investigated the influence of instruction on prospective secondary science teachers’ understandings about modeling in the context of a model-based instructional module. They reported that prospective teachers became more articulated with the language of modeling, but they did not exhibit full understanding of scientific modeling.

The present study constitutes another attempt to investigate the effects of a short instructional intervention on prospective elementary teachers’ skills to design science lessons with models. We first explain how we introduced our students to scientific modeling through building and testing dynamic computer models, and how a computer-modeling tool influenced their thinking about scientific concepts. We then discuss the effects of the instructional intervention on students’ skills to design science lessons with computer models. Specifically, the research was guided by the following questions: (1) Do pre-service teachers’ models have a correct structure? (2) How “real” or “naïve” are pre-service teachers’ scientific models? and (3) What types of modeling experiences (explorative or expressive) do pre-service teachers integrate in their science lessons?

2. Method

2.1. Participants

Forty-seven fourth-year pre-service teachers who were enrolled in a science education methods course participated in the study. Students were required to participate in 13 whole-class meetings and in 13 75-min lab sessions (about 15 students in each lab). For the lab sessions, students were working in groups of three. Prior to taking this course, students completed a basic computing course where they learned how to use several general-purpose software, and an instructional technology course in which they learned how to integrate educational software in the content domains. None of the participants had any previous experience with Model-It, the software that was used in this study. Two participants stated that they had limited experience with a different computer-modeling tool, but none of them had any prior experience with teaching science through models, or attended any course where the learning process focused on models or the modeling process and their relation to mental models.

2.2. The computer-modeling tool

Model-It, a computer-modeling tool, was used in the study. Model-It is a learner-centered tool for building and testing dynamic, qualitative models (Jackson, Stratford, Krajcik, & Soloway, 1994; Metcalf et al., 2000; Stratford, Krajcik, & Soloway, 1998). When using Model-It, the user first creates objects that correspond to the observable entities of a system, such as sun, soil, plant, air, and so on. As shown in Fig. 1, the system allows the user to associate an icon with each object, so that it is visually associated with what it actually represents.

Then, the user associates variable quantities with each object that are called factors. Factors define measurable or calculable characteristics of an object, such as, for example as shown in Fig. 2, light, water, growth, carbon dioxide, etc.
Finally, factors are designated as causal or affected depending upon the direction of the relationship between them. As shown in Figs. 3 and 4, Model-It supports a qualitative, verbal representation of relationships (Jackson et al., 1994). Relationships can model immediate changes, which are defined in terms of two orientations (i.e., increases or decreases) and different variations (i.e., about the same, a lot, a little, more and more, less and less).
After the creation of a model, the user may test it using graphical tools. Fig. 5 shows one testing tool, namely, the meter, which displays a factor’s current value at the current time step. A time step may represent a minute, or hour, or whatever time interval a user is able to conceptualize. If a factor is considered as an independent factor, its value can be adjusted while the model is running. The user may test a model at run time and observe
how it changes dynamically. There is also another tool called the simulation graph, which presents a line graph displaying how factors change over a series of time steps.

Obviously, the learners, when using the software, draw upon their own understanding of phenomena to define objects, identify variables, and create relationships. Then they test their models and, based on their interpretation of the outcomes, they revise them. Model-It supports students in making sense of complex systems and scientific phenomena, and enables them to build computerized representations, and thereafter test them and observe the simulated outcomes of the models (Stratford et al., 1998).

In essence, Model-It supports students in model construction by scaffolding them in transitioning from what they already know about an object or a phenomenon to building a model representing the object or phenomenon. Model-It assists learners in externalizing their internal models about a phenomenon by constructing an external representation of it. It also scaffolds model building in different content domains and can be used with diverse populations with different levels of expertise in modeling ideas or phenomena (Jackson et al., 1994). The idea of scaffolding was initially introduced by Wood, Bruner, and Ross (1976) in the context of adult–child interactions, where a more knowledgeable adult assists a child to complete a task that is out of his or her reach. Although, Wood et al. (1976) did not connect scaffolding to Vygotsky’s zone of proximal development, contemporary educational psychology has explicitly made this link. The zone of proximal development defines the area between what a learner can do on his or her own and the level of potential problem solving capability with the help of people or tools (Vygotsky, 1978). Software scaffolds are the supporting structures that are provided by tools to promote learning. For a scaffold to be effective, it must reside within a student’s current zone of proximal development and provide him or her with just enough assistance, so that the learner is able to perform the task. With the help of scaffolds, learners can complete more advanced learning activities and engage in more advanced thinking and problem solving. For the case of Model-It, two important criteria, namely, learnability and flexibility guided
the scaffolded design of the tool. The software is easy to learn and suitable to be used by learners of various skills and expertise. Research evidence has shown that Model-It can be effectively used with middle school students and for the training of prospective teachers (Stratford et al., 1998; Crawford & Cullin, 2004).

2.3. The context of the modeling experience

The instructor of a science education methods course (first author) in collaboration with a faculty member in instructional technology (second author) designed a two and a half hour modeling experience and studied how this experience effected pre-service teachers’ skills in constructing and incorporating models in science teaching. The second author directed and facilitated the instruction during the modeling experience. During the modeling session, the authors initiated a discussion about the need to construct models and their significance as tools for studying and understanding scientific phenomena. They then discussed the structure of a model and they specifically explained that a model consists of objects, variables or factors, and relationships. Then, students were asked to think about the phenomenon of the growth of plants and form hypotheses. Subsequently, the authors and the students, as a class, constructed a visual representation (in the form of a concept map) depicting the growth of plants. Thereafter, Model-It was used to build and test a model representing the growth of plants. The instructors explained to the students that Model-It was powerful enough to assist the model-building process through its scaffolds, (i.e., Plan, Build, and Test), and that they could think of the model-building process as consisting of three steps, namely, create objects, define variables, and build relationships. The model that students constructed consisted of four entities, namely, plant, sun, soil, and air. Then for each entity, they defined variables, such as, growth for the plant, light for the sun, water and nutrients for the soil, and carbon dioxide for the air. Subsequently, students were asked to think about the cause and effect relationships amongst the various variables. Initially, students suggested using linear relationships for all variables to indicate that an increase in the value of the causal (independent) variable will affect the dependent variable by about the same amount. For example, as the amount of water in the soil increases the growth of the plant will increase by about the same amount. It was interesting to observe that despite the fact that initially students suggested to use only linear relationships, they changed their minds after the instructors asked them to examine how Model-It graphically depicted relationships of various orientations (i.e., increases or decreases) and different variations (i.e., about the same, a lot, a little, more and more, less and less, bell shaped curve).

Then, the course instructors asked the students to test the model and control variables in order to test their initial hypotheses. The first reaction was related to the amount of light that a plant needs in order to grow. Specifically, students stated that they kept the amount of light constant to a very low value, while they changed the values of the other independent variables to higher levels. The results of this investigation showed that plants could grow with very little amount of light provided that the value of at least one of the other three independent variables continued to increase. These results made the students skeptical and doubtful about the “correctness” of the model. After participants concluded that the model was not close to the “real thing,” the instructors asked them to suggest how one could go about changing the model. Some students suggested that one could identify relationships among the independent factors. Other students felt that they needed to read
more about the growth of plants and about the conditions that need to persist for the four entities not only to co-exist, but also how to regulate the amounts of their variables, so that the growth of plants, as depicted by the model, can be as close as possible to reality.

The main purpose of this activity was to facilitate participants’ construction of knowledge regarding the use of models and modeling in science teaching and learning. The participants used the software and based on their own knowledge about the growth of plants they defined objects, identified variables, and created relationships. Then, they tested their models and attempted to revise them by comparing the simulated outcomes of the models with their own real-life experiences regarding the growth of plants. In essence, the purpose of this modeling experience was to immerse students in the idea of thinking and learning about scientific concepts through models, but the level of immersion in this authentic modeling experience was necessarily constrained by the available time in the science education methods course.

2.4. Data collection

For assessment purposes, all pre-service teachers designed and developed an ICT-enhanced sixth-grade science lesson with Model-It. Specifically, each pre-service teacher was asked to choose a topic from the sixth-grade curriculum and use Model-It to teach this topic by integrating the modeling activities in an 80-min ICT-enhanced lesson for sixth-grade students to be taught in a school classroom. Pre-service teachers’ lesson plans were analyzed with qualitative research methods (Merriam, 1988) using as guides the three research questions that were stated at the beginning of the paper.

3. Results

3.1. Use of software scaffolds

As mentioned previously, model building requires students to identify the important entities of a system, their variables, and cause and effect relationships amongst the entities’ variables. We emphasize here that the software enables learners to build models, but it does not coach them to build models that are conceptually correct. Consequently, it is possible to build a model with Model-It, which has a correct structure (i.e., entities, variables, relationships), but without any conceptual validity. Based on the data, 72% of the participants constructed models with Model-It that had a correct structure. The participants identified the correct entities and variables for the phenomenon under investigation and determined meaningful relationships. The remaining 28% found it difficult to identify appropriate entities and variables for the systems they selected to study.

This finding shows that model building is a rather complex task that requires deep thinking about the subject matter under consideration. Modeling requires the learners to accomplish the complex task of identifying important variables for each entity and to determine the impact of these variables on the system. What Model-It did for the students was to help them break down the task into manageable parts and, through the sequenced tasks of building and testing a model using the Plan, Build, and Test scaffolds, it provided learners with a language and a systematic process to think about and describe scientific systems. The software appeared to scaffold prospective teachers’ abilities to build models, explore them, and revise them. The level of immersion in the modeling experience
and activities was necessarily constrained by the available time in the science methods course. Obviously, the time devoted exclusively to model-related activities was limited, and not enough for almost one third of the participants who could not identify appropriate entities and variables for the systems they studied. This outcome does not seem surprising if one takes into consideration the fact that this was participants’ first modeling experience. It was expected that not all pre-service teachers would feel comfortable with the idea of model building as well as competent with the cognitive demands of building models for abstract scientific concepts and phenomena. Also, students’ limited conceptual understanding about the topic they selected to teach could have also affected their ability to identify entities and variables, and define relationships among the different variables. However, we did not examine students’ conceptual understanding of subject matter, because we assumed that students would not select topics that they did not comprehend adequately.

3.2. “Real” or “Naïve” models

Of the 47 participants, 13% constructed models with more than three entities, more than one variable per entity and correct relationships. The overwhelming majority (87%) used Model-It to construct models, which had two or three entities, one variable per entity, and linear relationships of the form “as X increases Y increases by about the same amount.” Jonassen (2004) noted that there is probably a “dynamic and reciprocal relationship between internal mental models and the external models that students construct. The mental models provide the basis for external models” (p. 4). Based on the fact that, almost in their entirety, participants’ models were “naïve” or over-simplistic, the results indicate that participants probably held naïve beliefs or naïve internal mental models about science content, and naïve beliefs about the epistemological aspects of scientific modeling. The participants’ limited exposure and involvement in model-related activities, and their tenacity to hold on to naïve beliefs and mental representations (Driver, Asoko, Leach, Mortimer, & Scott, 1994) prevented them from developing sophisticated computer models.

Moreover, based on the results, the participants could be classified as level II modelers according to the classification scheme of Grosslight, Unger, Jay, and Smith (1991). According to this classification scheme, level II modelers realize the purpose of a model, that is, they view models as related to ideas and that there is not a one-to-one correspondence with reality, or do not consider models “as little copies of real-world objects” (Grosslight et al., 1991, p. 819). Consequently, level II modelers’ viewpoints go beyond a simple copy theory epistemology, and they do realize that some aspects of a model may be wrong and need to be changed. What level II modelers do not realize is that a model is a tool to trigger thinking in a community of learners and not a representation of some phenomenon that is used by an expert to explain a complex phenomenon to a novice.

As novice modelers, our students created “safe” models that simply depicted their own subjective point of view of how a phenomenon could be modeled, and did not use the software as an idea-testing tool to investigate complex phenomena. They rather failed to recognize that models are representations of ideas about real-world objects or events, and not representations of the objects or events themselves. Similarly, they thought that different models are primarily means for communicating information about real-world events and failed to demonstrate competency at the highest or expert level (level III) in Grosslight.
et al.’s (1991) classification scheme. At this level, modelers understand that models are aids to understanding phenomena, and that this understanding is tentative and can be checked or verified by comparing the results obtained by manipulating the model with observations made in the real world. Moreover, expert modelers can understand that more than one model for the same object or phenomenon can result from different assumptions about the target. They also understand that different models are used to address different specific questions about the referent, while they recognize that models can be replaced by new ones that are better for answering questions and making useful predictions.

Despite the recognition that model-centered instruction accurately reflects the purposes and practices of modern science, the present results appear to corroborate previous research evidence indicating that students may not understand the nature of models or the process of modeling, even when they are engaged in creating and revising models (Carey & Smith, 1993).

3.3. Preferred modeling method

In their lesson plans, 27% of pre-service teachers preferred the expressive modeling method where they asked their students to build their own models. Of the remaining pre-service teachers, 65% of them used the explorative method where they asked their students to run a teacher-made model and draw conclusions based on their investigations, and 8% used both types of modeling methods. Specifically, the 8% of participants who used both modeling methods initially asked their students to build their own models to express initial beliefs about a phenomenon, and then provided them with different ready-made models of the same phenomenon that students had to compare and contrast with their own models.

These results indicate that the majority of the participants rather viewed models as a means for representing some object or phenomenon (the target) for pedagogical purposes (Crawford & Cullin, 2004). They consistently considered models as means to communicate information to their students about events and phenomena, and they did not understand the use of models as cognitive tools that can be used to represent an internal model and thereafter use this external representation to test hypotheses and theories. They also considered that different models capture different spatiotemporal views of objects or events rather than different theoretical views about them. This understanding contradicts the idea that models are constructed as tools for developing and testing ideas and explanations, and is not compatible with the dynamic nature of science, where ideas can emerge through a continuous and cyclic process of experimentation, evaluation, and revision.

4. Discussion and concluding remarks

The main purpose of the study was to investigate prospective elementary teachers’ knowledge about the use of models and modeling learning activities in science teaching and learning, after a short instructional intervention that lasted for two and a half hours. Despite the short duration of the instructional intervention and the small sample of participants, the results of the study are rather encouraging. Initially, pre-service teachers were completely ignorant about the role of models and modeling in science teaching and learning, but they were able, after the intervention, to use the scaffolds of Model-It and build models that were conceptually correct. There was also evidence that the
participants developed a more articulated way of thinking and talking about the role of models in science teaching and learning. However, the results showed that not all participants were able to construct sophisticated models and employ both expressive and explorative modeling methods in their science lessons. Many of the prospective teachers also acknowledged the fact that the experience was really interesting, but it was evident that students, in general, needed more time with either learning how to use Model-It, or with the process of learning how to construct a model. It may be the case that with more time and engagement in rich modeling activities most students at the end will be able to construct viable scientific models and become competent in teaching science through models. These results are in agreement with the results of other studies, which also engaged prospective teachers in the act of model building (Crawford & Cullin, 2004; De Jong & Van Driel, 2001).

It is our belief that if teacher educators undertake coordinated efforts in systematically integrating computer-modeling tools in science courses, then prospective teachers will understand science content and teaching better. The findings also suggest that further research efforts are needed to explore effective ways of how to gradually support teachers in achieving higher levels of expertise in constructing scientific models, understanding their significance, and integrating them effectively in real classroom practices. It is necessary to engage prospective teachers in extensive rich modeling experiences throughout their coursework in order to help them understand that scientific models are not mere representations, but actual tools for thinking and learning that play an essential role in scientific inquiry. Such an understanding or conceptual shift will also enhance their understanding of the nature of science and that learning with models is an important and valuable endeavor.

Overall, the results indicate that there is still a need to, further, examine prospective teachers’ understandings and uses of models (American Association for the Advancement of Science, 1993b). The present findings also indicate that different groups of students faced difficulties in understanding several aspects of models and the modeling process, such as the construction of models, their nature, and the process of evaluating and revising them. For example, some participants were not able to identify entities and variables for the topic they selected to study, while others built “naïve” models or tended to employ in their lesson plans only explorative models. These results suggest that enabling students to acquire knowledge about modeling is difficult and requires time, effort, and a clear understanding that there may be differential outcomes from model-based instruction. These differential outcomes may not be accounted by a uni-dimensional developmental progression, and a more accurate and useful view of modeling expertise seems to be necessary.

Despite the observed difficulties, intensive and coordinated efforts should be undertaken to help both pre- and in-service teachers understand the nature of models and the process of modeling, so that they help their own students learn about modeling by offering them opportunities to engage in scientific inquiry and modeling. Enabling students to engage in modeling has a large number of potential benefits that extend beyond improving content knowledge and inquiry skills, because it can also promote accurate and productive epistemologies of science. Obviously, understanding models and modeling helps students to understand the nature of scientific knowledge as a human construct, and that models may differ in their ability to approximate, explain, and predict real-world phenomena. Models are also useful in representing the probabilistic and tentative nature of scientific knowledge. Constructing more fruitful epistemologies of science may also help students
to reason better about scientific evidence as well as facilitate better integration of their conceptual knowledge (Gilbert, 1991; Songer & Linn, 1991).

Evidence from the present study is limited and inconclusive not only because the sample was small, but also because students’ involvement with models and the modeling process was very short. Nevertheless, the results point to the same direction as the existing research evidence from previous studies. Models are very useful tools that can enhance learning and understanding in science, but they are also an important part of the scientific process, and can improve learners’ understanding of the nature of scientific knowledge as a human construct that is tentative and probabilistic. The extent to which models are used in science and their potential impact on learning and understanding science coupled with recent technological advancements that brought computer modeling into the realm of everyday activities provide a challenge for further investigating their potential impact on learning and understanding science.

References


