Science Teachers' Competence on Model-Based Inquiry: A Review of Related Literature

Shiela L. Tirol
Cebu Roosevelt Memorial Colleges
San Vicente St.,Bogo City Cebu Philippines 6010
shielatirol32@gmail.com

Abstract. This review of literature explores the improvement of the knowledge of science teachersby looking at their modeling competence and Pedagogical Content Knowledge (PCK) of scientific models and modeling. Also, to connect past work on specific science practices to Model-Based Inquiry (MBI), emphasize MBI literature, and determine gaps regarding knowledge concerningMBI efficacy at the secondary and higher education levels. MBI is considered a relevant approach for developing students' knowledge of topics in science by engaging them in science practices. By involving students in genuine science practices, MBI promotes scientific literacy and thereby improves comprehension of how knowledge works or occurs. Modeling, explanation, and debate are essential science techniques for MBI students. Such activities have been examined one by one, with descriptions and studies from K-12 and postsecondary institutions. Each practice is examined for its implications and limitations.Educators must build their own modeling expertise in order to provide appropriate modeling prospects for their learners in the class, according to a previous work centered on promoting either in as well as preservice teachers' ideas about modeling. MBI is a successful educational approach for boosting student comprehension of science ideas.

Introduction

To identify what literature to review for this study, a series of questions led the investigation. The questions included the following: What theoretical framework supports MBI as an instructional design? What knowledge construct is important in guiding the thinking about teaching science content through MBI?What are the theoretical underpinnings that allows the examination of science teacher learning through a PD program to develop model competence and PCK? What research studies have been conducted to support the PCK of modeling and scientific models among teachers in science? The succeeding literature review outlines underlying theoretical perspectives for MBI and the research addressing the facets of model competence and PCK of modeling and models of teachers in science.

The majority of the review focuses on the teacher knowledge construct related to their model competence and PCK on models and modeling by defining it, describing how it has been conceptualized generally and for science teaching, describing its components and empirical research. Professional development as a means of promoting continued teacher learning is also discussed. This chapter ends with a review of studies, where research on PCK of science models and modeling will be reviewed to provide insight on the procedures and methods for examining this construct.

According to a recent study, preservice teachers' understanding of current theories and models can be enhanced through offering facts in a holistic manner, making assignments that integrate instructors' recent activities about simulations, then nurturing consideration center around such activities. Instructors become highly inclined to involve learners to building technical representations when they take chances to participate them to model development that have academic relevancewith them, and also reflect on real awareness as well as practices with showing procedures (Kenyon et al., 2011).

Although the effectiveness of the model-based learning approach has been already proven, previous studies were conducted in foreign setup and focused mostly on its effect on students' attitudes toward science and the improvement of learners' mental models. However, the possible effects of the Model-based inquiry teacher professional development on the model competence, attitude and beliefs of science teachers have not been studied in the Philippines setting. For these reasons, the researcher would like to determine the effect of the model-based inquiry teachers' PD in their model competence, beliefs and attitudes towards scientific models and modeling along with the instructors' perception in employing this strategy in teaching science. The result of this study can be used as basis of science teachers in developing a modified teaching unit aligned with the model-based learning approach.

Model-Based Inquiry.

MBI was utilized as a substitute for poor application of the scientific method in science education. MBI is conceived as a system of action including discourse that employs students further intensely with content and contains five properties of knowledge of science which states that concepts characterized in the arrangement of models can be tested, revised and explained, conjectural, and generative. Through model-based inquiry, it enables learners in putting actual concepts to the test instead of predicting the future, and it focuses on deep conceptual understanding rather than just generating predictions. A fresh reason and approach for developing an MBI curriculum was proposed by Passmore, Stewart, and Cartier (2009). Models are found in the center of their structure. MBI seeks to improve learners' deeper indulgent of models in science and modeling. Learners' participation in using models improve epistemic understanding about their ideas of the nature of scientific models.

A retroactive view emphasizes the model object's precision and coherence to corresponding event as an ideal representation of anything. Conversely, the model object could be used as a study tool to uncover new understanding of the phenomenon (e.g., Gouvea& Passmore, 2017). This prospective viewpoint enables one to make inferences about the model object's future behavior. Ebola virus illness transmission rate models and mathematical models for communicable disease characteristics represents the potential usage of replicas relating to hypothetical simulations. The emphasis must not be on a modeling of approximately as a completion in the underlying concepts; but, models must be for certain making meaning objectives (Passmore at al., 2014). Science practices associated with model-based inquiry can be traced from the current call for new standards to improve science education among our foreign counterparts. The next discussion centers around MBI as an instructional design set to enhance inquiry practices in science as meaningful reform efforts. The development related to how MBI was adopted and applied in science curriculum in the international setting allows an examination of its effectivity and possible adoption in science education in the Philippine context will also be discussed.

Science Practices in Models and Modeling

New standards have recently been recommended to progress science instruction. One fundamental aims of science teaching are to foster learners' habits of mind towards learning science, improve capacity of learners by engaging them in the practice ofscientific inquiry in an environment that allows them to think scientifically. However, learners have only had a limited exposure to these scientific approaches through traditional science teaching. To completely appreciate science, a learner needs acquire skills, experience, and knowledge about the subject. Model development and application, explanation formulation, and evidence-based arguments are all examples of this (Table 1). Scientific practices are knowledge and abilities that are used to develop, extend, and enrich our knowledge of the world. Science must be accessible to learners of all ages and backgrounds in order for them to get a solid indulgent of science discovery (Windschitl et al., 2008).

Discovering new knowledge is one of the goals of being a scientist (Osborne, 2014). A science student, on the other hand, has no such ambitious expectations, but rather seeks to understand what is already known. Therefore, survey approaches found in teaching function a better drive when they are used in creating knowledge of procedures, structures, or epistemic criteria in addition to content knowledge. Not simply methods and data, but also a profound knowledge and enthusiasm for science should be the goal of inquiry. The problems with educational inquiry boil down to a communication issue, specifically an absence of a consistent semantic to define investigation (Osborne, 2014). Several teachers make the error of thinking that "hands-on" activities are sufficient for inquiry. On the other hand, some educators feel that the ultimate purpose of all scientific classrooms should be unrestricted inquiry. In actuality, inquiry entails conducting science in the manner of scientists, which varies by field but always involves making statements about the natural world based on facts and evidence. Occasionally, it entails practical undertakings in the laboratory, and other times it entails open inquiry, in which students create their own questions besides inquiries; nevertheless, none of these descriptions encompasses inquiry completely (Crawford, 2014).

When compared to standard lecture, active learning has garnered a lot of consideration in higher education, boosting student performance on exams and conception accounts. Through active learning, students construct their own understanding, overcome difficulties, then assess their own thinking. Another word being frequently misunderstood. According to Osborne (2014), the process of science teaching enables the teaching of science inquiry and overpowers various conventional problems related with science teaching through inquiry. It is stated that these approaches provide a compact style of teaching that may be effectively applied in postsecondary education and enhance adult students' literacy in relation to science. An account for the strategy mentioned will be provided in the following sections, along with studies from K–12 and postsecondary education. The nature of science models and scientific modeling is discussed first andpresent several definitions or assumptions to the concept of MBI and its applications. It is followed by the different accounts in the literature that explains in what way demonstrating is practiced in the classroom as well as the way students construct explanations and of special interest in K to 12 and tertiary education. The suggestions and restrictions will be presented tohighlight the nature of model and modeling practice, as well as how students create scientific explanations.

The Nature of Modeling and Models. It's hard to consider about science devoid of replicas and simulations (BailerJones, 2009). Several types of models exist in science, respectively with its own establishedpresentations. Furthermore, the functions of models have many different meanings: a portrayal, a method to simplify, a standard for presenting information, a prototype, an intermediary in explaining theories, a tool in making predictions, or as an object for gaining novel comprehensions (Passmore, Svoboda Gouvea, &Giere, 2014).

It is impossible to describe the term model ontologically due to the diversity of models and their meanings. Instead it is advocated as an epistemic methodology, demonstrating the concept of determining as to whether a person is a model or not is a matter of personal preference and situational assessment. As a result, there exist no clear response with regard to the common ontological issue of what a model is: What qualifies something as a model? (Mahr, 2011). From an epistemological standpoint, this influences the thinking processes with models and permits individual to discover connections found important for judging the structure and the model function. When describing something of a model of science, the connection concerning a model, associated objects as models, and the starting item is important. First and foremost, being often a representation of something, a model represents a phenomenon, an object as a model gains their significance. The properties of a phenomena are transmitted to the model object during the construction of a model. Next, each model serves being a template for a certain thing and as a replica,it will be utilized as a standard to express identified elements of occurrences in the adoption of a model (Mahr,2008, 2011).

Modeling Practice in the Science Classroom. Analogous, explicit representation of a phenomenon are known as conceptual models (NRC, 2012). A prototype should also "be comprehensible and explanatory, compatible to prior knowledge, interactive, constantly reviewed for consistency with contemporary model and empirical evidence, accept the possibility of multiple relevant evidence for the same occurrence, as well as being the reference to imminent studies. Whereas some sorts of representations, such as mental or mathematical models, are employed by experts, MBI focuses on concepts, usually visual, designs. Through this technique, models are used in interpreting certain environment within a specific context. Modeling refers to the learner or an entire class developing prototypes as symbols of processes or structures, then consuming those models in explaining or predicting events (NRC, 2012). The studies in the next section focused on modeling practice in K-12 and postsecondary educations with particular focus on models as explanations.

Justification. The activity of justification refers to "concrete presentations or theories of such an event and occurrence, maybe through the medium of an assertion prototype for the system under examination" (NRC, 2012, p. 52). When science practitioners or students utilize data and concept to describe the mechanisms underlying a natural phenomenon or event, they are said to be "constructing an explanation." Cause-and-effect mechanisms are important for successful explanations. These explanations are scientific, and they're used to figure out what's going on right now, infer details about what happened in the past, and forecast what will happen

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in the future (NRC, 2012). Students who participate in explanation get a greater comprehension of concepts and underlying processes, as well as the ability to handover information to clarify modern phenomenon.

In the K to 12 education. Models are described as better predictive tools by Schwarz et al. (2009), and they evolve as knowledge grows. When students in 5th and 6th grades modeled, they improved in both parts of the exercise. Learners seem to have been able to improve their ideas so that they were more reliable and included stronger causative factors, as well as use them to predict fresh events. Students also improved their modeling skills, progressing beyond descriptive to explanatory and presenting justifications for model adjustments. Modeling has been found to be an excellent way for elementary school pupils to comprehend and explain natural processes.

Manz (2012) discovered that simulating ecosystem functions in a natural backyard environment aided the formation of understanding about patterns noticed in plant growing conditions in a study involving third grade pupils. Both modeling abilities and ecological knowledge were gained at the same time and in a coordinated manner. As the two case studies above demonstrate, successful modeling activity in the classroom can help young scientists make sense of their surroundings in early grades. Similarly, the introduction of modeling to 11th-grade students in chemistry aided in the understanding of the theoretical knowledge of the atomic structure as well as molecules when students studied various similar models then assessed their potential to explain how matter nehaves (Harrison &Treagust, 1998). However, rather than the modeling process, this study focused on the discussion of current models for teaching materials. A study involving a design-related evolutionary biology program conducted for 9 weeks was developed high school learners. The researchers provided a lot of qualitative data to describe what it means to understand evolution, however it was not an empirical research, and researchers didn't try to evaluate foundational understanding. More research in secondary scientific education is needed in order to understand overall how models contribute in formulating the fundamental learning among high school students (Passmore et al., 2002).

Learners are more successful in absorbing content when they create their own explanation (Chi et al., 1994). Another research looked at how urged justification, drawing on prior research impact on forming spontaneous explanation among college students in physics (Chi et al., 1989). Students in 8th - grade biology had been instructed to review a section about the circulatory system from a textbook and describe the interpretation of single phrases and the construction, purpose, and movement of circulatory parts of the system. Practicing explanation showed a big influence in the formulation of knowledge on these topics, regardless of how competence the learners are. Learners improve their thorough knowledge of the topic when they are encouraged to articulate what they are learning, which leads to better exam results. According to Chin and Brown (2000), 8th-grade students that exhibited deeper analysis were developing possible explanation.

The results suggest that encouraging students to describe mechanisms during activities can assist teachers in encouraging deeper thinking and understanding. Science is all about explanation, and scholars work hard to explain procedures and events. In order to participate in meaningful research in various science studies, learners are required to comprehend procedures and occurrences. Science education requires explanation and a precise statement of justification should be applied to achieve such goals (NRC, 2012). On the other hand, educators have a limited understanding of scientific explanation and Braaten and Windschitl (2011) respond by synthesizing explanatory concepts out from similar studies, which several teachers utilize to improve or enhance current work. Some of these concepts are explanations as explication, causality for explanation, and justification through explanation. In order for explaining to be the norm in scientific classes, it must be clearly expressed to educators. One of the most effective strategies to improve science classroom practice is to shift from merely describing observations to formulating justifications that explain action.

***In postsecondary education*.** Student modeling participation is rarely studied in postsecondary education. In a study, there were students in science engaged through a three-hour experiment utilizing a working prototype. Learners have been provided black-colored box to be filled with water while watching with a funnel. Students made a visual model from the inside of the box after collecting observations. There were significant improvements in structure, explanatory and predictive character, limit and validity determination, and diverse illustrations in students' prototypes. Whereas it remained shown that this sole model application improved students' grasp of scientific demonstrating and, as a result, their ability to comprehend complicated science subject, the students "did not exhibit a conceptual understanding. Furthermore, the study does not involve learners through modeled tasks such as evaluating alternative models or utilizing models to describe or forecast natural systems or events, as recommended by the Framework (NRC, 2012).

Throughout one semester-long introductory biology course, used models as anapproach. Through case studies,students built visuals in demonstrating their learning diversity in genetics, phenotype variability, as well as population health. The accuracy and effectiveness of these models to describe molecular causal pathways for diversity and evolution were evaluated. Students' models were more comprehensive, sparse, and precise as they repeated modeling of numerous occurrences. These findings are encouraging; but, because a single part was only examined, itsmodel impact on student fundamental conceptionwill not be identified. Furthermore, another study's findings fail to discuss repetitive model within the same occurrence, despite the fact regarding continual criticism could help students develop knowledge with the methods described in the process. The purpose of models to explain and forecast occurrences was never examined including model revision or model evaluation versus alternatives in higher education (Speth et al., 2014).

These advantages can also be measured in adult students. In an intermediate chemistry course, involving students in the construction of explanations was found to boost student understanding (Teichert & Stacy, 2002). Non-chemistry majors were divided into two groups in an empirical investigation. Students in the intervention group took part in two talks in which they were asked to describe their thoughts on thermodynamics subjects. The control group took part in the talks as well, but had the topics presented to them by an expert. In the test conducted by the American Chemical Society, students receiving the interventions outdone their classmates in the control group. When comparing the intervention and control groups, interviews revealed that learners in the experimental group had a higher level in knowledge.

Implications and limitations. Modeling may be a powerful tool for demonstrating students ' thinking as well as a propagative tool for explaining besides predicting occurrences (Windschitl, Thompson, & Braaten, 2008). Modeling is a subject that is frequently misunderstood. The modeling approach should be employed in well-organized multiple connections to deliver perspective. Despite having collectively produced numerous reasonable representations for an occurrence, college students failed to appreciate model potential in many valid prototypes. Moreover, a hangover from learners' past indoctrination to expect lone correct answers or a soletechnique. As a result, both modeling's nature and practice must be corrected (Schwarz et al., 2009).

Four restrictions on student explanation approaches for sensemaking are described by Rittle-Johnson and Loehr (2016). First, some learning domains benefit from explanation more than others. These include those that are led by heuristics and general principles. In general, explanation enhances causal mechanism transfer but diminishes detail recall. Second, the type of material that is being explained may hinder its impact. When there are misconceptions about a phenomenon, explaining it simply attracts attention to and reinforces those assumptions. Third, the type of knowledge gleaned through explanation can be influenced by the suggestion given to pupils. Rittle-Johnson and Loehr (2016) propose why justification stimuli help other people understand ideas and causal mechanisms, but not how they help people understand how to use those things. Finally, explanation has a significant interval restriction. Additional research is required to see if additional, less time-consuming methods of instruction can produce the same outcomes.

If explanation is delivered in a disorganized manner, it may actively hinder knowledge (Rittle-Johnson et al., 2016). This tendency for learner answers to propagate errors highlights relevance in mixing training of extra tasks, including arguing, in order to build correct notions whilst making sense. Despite these shortcomings, explanation increases a wide range of learning outcomes. The importance of explanation in increasing causal mechanism transfer and knowledge (Chin & Brown, 2000), as well as developing deeper conceptual comprehension, is of special interest to MBI (Teichert & Stacy, 2002). In the next section, the advantages of modeling will be highlighted in science instruction.

Advantages of Modeling in Science Instruction

Emerging research studies shows having pupils engage in modeling activities helps their learning. According to a study, students who participate in modeling have thorough grasp of the matter with the capability in solving unique challenges (Lehrer and Schauble 2005). Modeling classes, according to other research, may help students connect with science's epistemic goals and develop more complex notions about the technical inventiveness (Windschitl et al. 2008). Modeling has a proven track record of assisting large transformation projects in science teaching. As model approach grow more popular, there is a growing need to explore how modeling is employed in scientific research and how these techniques align with educational objectives.

Mostly in science education literature, both resources and model purpose, as well as the corrective distinctions occurring through this method, are undefined to a large extent. Through a study, the authors deliberately restricted in a study, the basic explanation in the modeling exercise rather than attempting to reason intended for variability in demonstrating approaches (Schwarz et al., 2009). Prototypes are modest, mental demonstrations in describing or predicting things in their work. However, neither the differing purposes of explanation and prediction, nor in how the ease or abstract nature of models may vary, are discussed in depth. Other authors define "model" as a simpler system (a model) which enables one to investigate complicated structure, as an organized sequence of abstract concepts, a demonstration knowledge (data), or a system conceptual framework. Such examples demonstrate that modeling can be utilized for a variety of reasons, but the differences between these have yet to be established in the school science literature. These various models contain varying interpretations and applications, because they interact with other scientific processes in a variety of ways. Whereas these studies are great starting locations for attempting to introduce concepts into the classroom, it is argued that without such a deeper understanding and function of models and model construction in science, modeling risks becoming akin to answering the quest for inquiry in teaching science, where its discipline's significance becomes broad and dispersed losing its utility. These techniques frequently were implemented in overly simple measures, limiting prospects for complex scientific thinking and even promoting anti-authentic perceptions of science (Rudolph 2005). Model practices were treated in most part without regard for the various limits of countless uses of models. When models are intellectual aids, it's important to consider what kind of thinking they can aid and for what purposes. Learners frequently were asked for contemplatingmodels with no rich appreciation of modeling being such useful undertaking. As a result, there is a need to apply ideas from the philosophy of science research to an examination of a modeling-based academic opportunity for science teachers to unpack the variety of intellectual approaches and epistemic goals that it can support, as well as the relationships between them. The following section discusses the challenges of model use in science and provide information of existing practice of MBI and the aspects that hinders its positive effects.

The challenges of model use in science

Due to challenges, it's possible to assume that modeling and simulations are utilized in science teaching in similar way. People may mistakenly believe that models and model construction are used in teaching science in much the same way. Students need to be able to use modeling as research tools in a constructive and inquiry-based approach to scientific enquiry, which includes developing ideas and predictions as well as gaining new information and knowledge of scientific processes. UpmeierzuBelzen&Krüger (2010) state that students must reflect on the practice and have the drive and social competence to apply their knowledge in problem-solving situations. "A key procedure in all social thinking in addition to a vitally important emphasis for education defines models according to Gilbert &Justi, (2016). Modeling approaches must be incorporated in science classes if complete scientific education is to become a certainty.

Improving teachers' epistemic knowledge and skills in modeling-based instruction is critical to achieving the goal of growing students' scientific modeling competency. The following discussions present a framework for how teachers gain model expertise in science classrooms, taking into account previous studies on improving aims to improve the quality and educators' professional development on building models, as well as the significance of classroom quality of teaching for meaningful and effective teaching and learning. The discussion commences through an overview of professional development framework which winds up with Evan's model of professionalism and professional development. It is followed by a discussion of how to measure modeling competence and PCK of models and modeling by science teachers. How teachers incorporate MBI into practice through the development of teaching units using the 5Es model concludes the discussion. The goal of the subsequent discussions is to provide delineation of modeling-based teaching competence.

Synthesis

Multiple methods for supporting teachers' learning and modeling techniques have been discovered through research. 'Sustained dialogue on epistemological ideas' is required to support educators' development in terms of accepting then participating in model-based educational practices (Windschitl et al., 2008, p. 362). Continuing education, formal classroom encounters that make modeling processes clear may increase preservice in addition to in-service teachers' competence and self-confidence to support learners' systematic modeling in their classes. It comprises setting up then supporting specialized demonstrating activities for teacher educators, which enable prospective teachers to clearly study about and participate in the practice of modeling through undertakings and reflection, preparing them for ultimate classroom adoption of modeling in science. According to study about in-service educators, parallel assistance can be provided in longer term faculty development activities, that focus on educators considering logical models (Justi& van Driel, 2005). However, little is known about how science instructors perceive model-based teaching and learning and how they need support to put it into practice.

Conclusion

Modeling, explanation, and debate are just a few of the basic science methods that MBI use to involve learners in ways that are in akin with genuine science discipline. Learners can employ demonstrating skills and its function to explain and understand natural events, as well as challenging or abstract themes. Students can gain significantly better comprehension of science ideas via the exercise of constructing explanations (Richmond, Parker, &Kaldaras, 2016). Students' conceptual knowledge and evaluation scores both improve when they engage in scientific discourse (Sampson, Enderle, Grooms, & Witte, 2013). Students' conceptual knowledge remains enriched, in addition to profounder thinking being elicited, when these techniques are used in conjunction through the MBI framework.

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