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entitled

Preservice Teachers' Ideas About Scientific Modeling and Model-based Inquiry During A Methods of Teaching Course

by

Roseline Nyaboke

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Doctor of Philosophy in Curriculum and Instruction

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An Abstract of

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Scientific modeling is a scientific practice that uses models to prepare elementary and middle school science teachers to engage students using scientific inquiry. Model-based inquiry (MBI) is a pedagogical teaching approach that engages students using scientific inquiry during scientific modeling. However, preservice teachers lack understanding of scientific modeling since they struggle to engage students while teaching using models. Also, the preservice teachers lack vital information about modeling when exposed to model-based teaching since they possess limited views when exposed to model-based teaching.

Therefore, this study focused on exploring what the graduate science preservice teachers know about scientific modeling and MBI during a Methods of Teaching Course. In this study, five participants participated initially, and only three completed the study. The interviews were conducted at the beginning and the end of the scientific modeling activity, which required the participants to share their knowledge based on scientific Modeling, and MBI. The participants also completed the scientific modeling assignment, which required them to describe ways they could use while teaching scientific modeling. The study engaged an exploratory case study to analyze the data. The findings indicate

that the participants understood scientific modeling before being introduced to scientific modeling activity by portraying the knowledge of evaluate step of scientific modeling. However, the participants did not understand the construct and revise steps of scientific modeling. Also, the participants' knowledge of scientific modeling improved after the scientific modeling activity through better explanations during the evaluate steps of scientific modeling, but they did not understand the construct and revise step of scientific modeling. Additionally, the participants exhibited knowledge of all the stages of MBI: teacher planning for students' engagement, teacher eliciting students' ideas, teacher supporting students' ongoing changes in thinking, and teacher and students pressing for evidence-based explanations before they were introduced to scientific modeling activity; however, they were limited to the ideas of teacher planning for students' engagement and teacher and students pressing for evidence-based explanations.

Additionally, the participants improved their ideas of MBI at the end of the scientific modeling activity since they demonstrated better explanations in all the stages of MBI. However, the participants were limited to the ideas of teacher planning for students' engagement and teacher and students pressing for evidence-based explanations. Further, the scientific modeling activity enabled the participants to describe better ways of teaching scientific modeling classes. This study indicates that the participants are not ready to teach scientific modeling and MBI since they did not understand all the steps of scientific modeling and their knowledge of MBI was limited.

This dissertation is dedicated to our most loving and caring God for His immense favor towards me. To my husband, Robert Cacic, thank you for the love, care, and emotional support throughout. Without forgetting my late father, Lawrence Nyabengi Ndanya, thank you for nursing me with affection, love, and support during your earthly life (1950-2012). I know you would have been a proud father to witness this outstanding achievement, but I have hope that soon we will meet in the resurrection morning. Finally, this dissertation is dedicated to all teachers for transforming and nurturing all talents.

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Table of Contents

List of Tables

Chapter 1

Introduction

Science, Technology, Engineering, and Mathematics (STEM) has emerged to discoveries and technological advancement (Snyder, 2018). STEM education requires diverse skills and has been given focus by scientists and educational researchers (Zaher & Damaj, 2018). 21^{st}-century skills include creativity, critical thinking and problem solving (Laar, Deursen. Dijk, Haan, 2017). The 21^{st}-century skills have been linked to scientific practices (Windschitl, 2009) in that these skills are achieved by engaging students in the learning of scientific practices (Windschitl et al., 2008).

Science practices are behaviors that scientists engage in when investigating to enable them to construct models and develop theories about a phenomenon (the NGSS Lead States, 2013). There are eight scientific practices, and these are asking questions for science, developing and using models, planning and carrying out investigations, constructing explanations, using mathematics and computational thinking, analyzing and interpreting data, engaging in argument from evidence and obtaining, evaluating, and communicating information (the NGSS Lead States, 2013; NRC, 2012; Merritt & Krajack, 2012; Bybee, 2011). K-12 students must demonstrate their scientific practices ideas in class while doing science activities (Berland, Russ & West, 2020). However, the national and international metrics data show that in the United States of America (USA), students lag behind other advanced industrial nations in science classrooms (Desilver, 2017). For example, in the USA, science students cover a lot more in school than in other countries, and what these students cover does not reflect their understanding in school

(Windcshitl et al., 2008; Schmidt, Borroughs & Cogan, 2013). A significant concern has been raised about the state of science education in the USA (Bedward., Wiebe., Minogue., Carter, 2009) and a call for change in the entire system of science education (National Science Foundation, 1996). Currently, a focus on science education in the USA is on scientific practices (Erduran & Dagher, 2016). One of the scientific practices that science education researchers have emphasized is developing and using scientific models (Davis., Nelson., Hug., Kenyon., Cotterman., Tao, 2010; Baybee,2014) because scientists use models when making a scientific inquiry (Skjoid & Schwarz, 2012). Scientific models are forms of inquiry in which their features and use of knowledge creation result from investigating a phenomenon (Campbell et al., 2019). Scientific models may include drawings, physical replicas, analogies, mathematics representations, and computer simulations, in the sense that each of these models represents a system of questions asking and developing explanations (Huang et al., 2018).

Although the development and use of scientific models are recommended as necessary in science education, there are minimal studies done on the ability to develop these scientific models (Cheng & Lin, 2015). However, the preservice teachers have a deficiency in understanding scientific modeling (Cheng & Lin, 2015; Kenyon, Davis & Hug, 2011; Davis et al., 2010). As a result, preservice teachers need to promote students learning of scientific modeling and evaluate students' scientific models (Davis & nelson, 2012). However, acquiring the knowledge of teaching scientific modeling is challenging, and educators need a guided practice to engage the preservice teachers (Schneider, 2012). Therefore, this study is achieved by conducting and engaging the preservice science teachers with the scientific modeling activity, including the models' features, steps of scientific modeling, and the stages of Model-based Inquiry (MBI).

Study Purpose

This study focused on two aspects of scientific modeling; to explore what the graduate science preservice teachers know about scientific modeling and what they know about Model-based Inquiry during a method of teaching course. The study posed the following research questions:

1. What do the University of Toledo (UT) graduate preservice science teachers know about scientific modeling during the methods of teaching science courses?
    a) What do UT graduate preservice science teachers know about scientific modeling at the beginning of the scientific modeling activity?
    b) What do UT graduate science preservice teachers know about scientific modeling at the end of the scientific modeling activity?
    c) How do UT graduate science preservice teachers understand of scientific modeling change at the end of the scientific modeling activity?
2. What do UT graduate science preservice teachers know about Model-based inquiry during the methods of teaching science course?
    a) What do UT graduate science preservice teachers know about Model-based Inquiry at the beginning of the modeling activity?
    b) What do UT graduate preservice science teachers know Model-based Inquiry at the end of the activity?
    c) How do UT graduate science preservice teachers understand Model-based Inquiry change at the end of scientific modeling activity?

d) How do UT graduate science preservice teachers understand Model-based Inquiry and the assignment change at the end of the scientific modeling activity?

Significance of the Study

This study creates an insight into science teachers to understand that the understanding nature of science is critical to understanding the knowledge of scientific modeling. Also, this study creates an awareness in science preservice teachers that the knowledge of scientific modeling is fundamental to the understanding and teaching of MBI. Also, this study would be helpful for science preservice teachers to know how the designed instructions of scientific modeling can impact students' knowledge of scientific modeling. Additionally, this study will enable preservice science teachers to understand that their preparation for teaching scientific modeling is essential in their content areas. Finally, this study will point to specific instructions that educators and researchers need to use when designing a class for science preservice teachers and carrying out an investigation with science preservice teachers.

To understand the knowledge of scientific modeling and Model-based Inquiry about preservice teachers and their significance in science and classrooms, the literature was examined with its related research to gather any possible information about preservice knowledge about scientific modeling, which involved the four steps of scientific modeling: construct, using, evaluate and revise in order to give an insight of Model-based Inquiry, which also involved the four stages of scientific modeling: teacher planning for engagement, eliciting students ideas, teacher supporting students on-going changes in thing and pressing for evidence-based explanations.

Chapter Two

Literature Review

The steps of scientific modeling and stages of model-based inquiry have provided ideas on the preservice teachers' knowledge of scientific modeling, and Model-based Inquiry could be studied. As a result, this section presents a conceptual framework that supports the growth of teachers' knowledge of scientific modeling and Model-based Inquiry. The constructs that guided this dissertation work are steps of scientific modeling that comprise construct, using, evaluate and revise. Also, the four stages of Model-Based Inquiry (MBI), namely: teachers planning for students' engagement, teachers eliciting students' ideas, teachers supporting ongoing changes in thinking, and teachers and students pressing for evidence-based explanations.

Conceptual Framework for Scientific Modeling

Scientific Models

The description of models represents a variety of entities (Passmore, Gouvea & Giera, 2014), and in this study, models are defined as external representations (the NGSS Lead States, 2013; Krajcik & Merritt, 2012; Lee, 2018; Oh & Oh, 2011; Windschitl & Thompson, 2006). In science, scientific models are forms of inquiry in which the features and use of knowledge creation come from doing an investigation of a phenomenon. Also, in science, the term model has been used in two similar ways. The first one is conceptual or mental models or ideal models, which is a way an individual understands a phenomenon. The second type of model is the expressed model, which is shown, for example, in the form of diagrams or descriptions of the ideal model (Kenyon et al., 2011).

Scientific models may include drawings, physical replicas, analogies, mathematics representations, and computer simulations, in the sense that each of the models represents a system of questions asking and developing explanations (NGSS the Lead 2013, The National Academic Press; Gray & Klyve, 2018). However, students need to understand the classifications of models because it serves as a blueprint for students to identify and understand the roles of models, functions, models limitations, and create an avenue for them to think and link model constructs (Chittleborough & Treagust, 2009). Additionally, students need to understand all the rules governing their science models. For instance, scientific models need to be evaluated based on the available evidence (Kenyon et al., 2011). Further, learners must understand that during scientific modeling, diagrams and pictures play a role in science when describing a specific phenomenon (Campbell, Oh & Neilson, 2013).

In addition to understanding scientific model features, students must develop inquiry competence in designing scientific models to demonstrate the physical observation of a phenomenon and understand the limits to which scientific models work (Chiu & Lin, 2019). Consequently, students need to know that all scientific models share some similarities in which a scientific model is a "representation of a phenomenon, an object, an event, a concept, a mixture of entities, a device, a theory, or even a system either in a concrete form or a composition of abstraction for different purposes in science education" (Chiu & Lin, 2019).

Types of Scientific Models

Concept Map. Concept maps are pedagogical tools used to create a visual representation used to represent students' ideas and create a connection between these ideas or concepts (Dowd, Duncan & Reynolds, 2015). Using a concept map is not used directly in the literature as an assessment of scientific models; however, concept maps are used to represent concepts or prepositional meanings that learners possess before they go through class instructions and after (Everett, Otto & Luera, 2009). In addition, a concept map involves a "graphic representation of the relationship among terms" (Valides, Yin, Tomita & Ruiz-Primo, 2005), which allows learners to make their visual representation and make connections between the concepts (Dowd et al., 2015).

Uses of Concept Maps to Students. Concept maps enable students to develop critical thinking and establish connections among studied words or terminologies. Also, concept maps would allow students to organize their thoughts and develop a clear picture of the relationships between terms meaningfully**.** Additionally, concept maps enable students to develop their thinking deeply upon reflecting on their understanding. Finally, concept maps act as a unique tool to allow teachers to evaluate students' understanding.

Visual Models. Visual models represent items of scientific ideas connected, and examples of visual models are photographs & diagrams (Evagorou, Erduran & Mantyla, 2015). Visual models enable scientists to interact and describe a complex phenomenon that is unobservable (Evagorou et al., 2015). In addition, visual models give students knowledgeable thinking, which enables the teacher to understand their students' conception of science ideas (Luckie, Harrison, and Ebert-May 2011).

Mental Models. Mental models represent some domain or situation that supports understanding, reasoning that is not directly experienced, and prediction of a phenomenon (Gentner & Stevens, 2014; Kenyon et al., 2011). Mental models may also represent a hypothetical situation to aid the learner in providing explanations and making a prediction (Treagust, Gail & Thapelo, 2017). Mental models are created internally through the interaction of the individual and the aspects whose information is obtained by doing activities such as problem-solving and engaging in drawing (Lajium, 2013). When students interact with models, it enables them to generate their mental models (Treagust et al., 2017).

Mental models enable understanding what an individual acquires when seeing, during instruction, and when concluding. Mental models also help to compare the individual mental models and the physical world. Finally, the mental model helps understand the behavior and determine the pre-service science teachers' future (Tatar, Feyzioglu, Buldur, Akpinar, 2012). Although mental models are advantageous when learning, they have their weaknesses. For example, students' models may not be the same as scientific and teaching modeling, creating a misconception. Also, students may not acquire an entirely mental process but pieces of it, which might limit students from not fully possessing the required mental models (Lajium, 2013).

Scientific Toolkit. Scientists use the scientific toolkit to describe the purpose of scientific modeling. A toolkit is "materials and experiences used to facilitate prospective teachers' critical reflection on science teaching and learning" (Nichos, Tippins & Wieseman, 1997). Additionally, the scientific modeling toolkit is one of the Next Generation Science Standard (Windschitl, 2013).

Further, the toolkits are designed for teachers to develop scientific knowledge and provide their views of science teaching (Nichols, 1997). Even though the toolkit has been considered helpful to teachers, they still think instructional toolkit as an alternative for learning and instructional practice rather than as a primary model (Windschitl, 2006).

When teachers consider a toolkit as an alternative, they lag in the consensus of the understanding conceptualization of scientific methods of inquiry. Teachers who are hesitant to use the toolkit may not encourage the features of classroom inquiry and their variations. Features of classroom inquiry include: "learners engage in scientifically oriented questions, learners give priority to evidence, learners' formulae explanations from evidence, learners connect explanations from evidence, learner connects explanations to scientific knowledge, and learners communicate and justify explanations" (Alozie, Moje & Krajcik, 2010, p. 29).

Using a scientific toolkit may enable the pre-service science teachers to practice the use of the toolkit while delivering the content to expand their scientific theory and practices for the benefit of the student.

Features/ Characteristics of Scientific Models. For students to fully develop and use models, it is beneficial to understand the features of models. Students' conception of the features of models may enable them to recognize and appreciate the role of models, their purpose, and their limitations (Treagust et al, 2002). The features of scientific models are stated in the Ambitious Science Teaching and NGSS (Windschitl, Thompson & Braaten, 2008; NGSS the Lead, 2013), and these features are:

1. Scientific models must signify a phenomenon.
2. Scientific models should contain detailed information about a specific event under certain conditions.
3. Scientific models should enable students to visualize what is written on a paper and make a connection with what is modeled.

4. Scientific models entail both those features that can be seen and those that are not seen.
5. Scientific models should meet the quality of reversibility in that all the processes involved should be able to be tested and show the relationships between them.
6. Scientific models may not mean the whole world precisely because other features might be observable while others might be uncertain. Nevertheless, it is imperative to understand how each model is represented and how it works.
7. Models are full of approximation and assumptions, and therefore students must keep working on their models as they refine them.

Uses of Scientific Models

Science education aims to engage students with sense-making (Passmore et al., 2014). For students to learn and understand science, they must appreciate scientific models by developing them and using them the way they are reflected by scientists (Schwartz & Skjold, 2012). Therefore, models serve as a meditational tool to unify observed events and theoretical ideas by explaining the features of a phenomenon (Campbell et al., 2019). Second, science models are used to represent a system or part of the system under study, aid in the development of questions and explanations, generate data that can be used to make predictions, and communicate ideas to others" (NGSS the Lead, 2013). This enables scientists to use models when making an inquiry which yields models development due to performing an investigation (Skjold & Schwartz, 2012). Third, models explain a phenomenon that leads to new knowledge production (Kenyon et al., 2011). Finally, models provide a view of how things work and how they are used to make predictions (Lee, 2018).

Advantages of Using Scientific Models in Class. There are advantages associated with using scientific models in the class. First, students must learn that scientific models are used to test an idea concerning the observations that are available in the real-world (Windschitl et al., 2008). Second, scientific models enable students to view and think about a natural phenomenon (Krajcik & Merritt, 2012; Schademan, 2014; Carr, et al., 2019; Windschitl et al., 2008). Third, models aid students in identifying patterns in a natural phenomenon when organizing data (Carr et al., 2019). Forth, models are essential in organizing the cognitive activities of students who practice science (Passmore & Cartier, 2009). Fifth, models facilitate students' understanding of things that are not directly seen but are assumed to be accurate (Windschitl et al., 2008). Finally, models are essential to students since they aid in explaining scientific concepts (Treagust et al., 2002).

Despite the stated advantages of scientific models in class, it can be challenging for students to be knowledgeable about scientific models if their teachers are limited to their knowledge of scientific modeling. It is noted that teachers possess a limited conception of scientific models because they do not understand the role of models as explanatory and predictive. For instance, (Schwartz & Skjold, 2012) claims that elementary and middle school teachers hold limited views that the use of scientific models aids in students understanding scientific content, and these conceptions limit teachers to the use of scientific models in class (Davis et al., 2010).

When teachers do not fully understand scientific models, students will also not possess the knowledge of scientific models required. For example, Schwartz & Skjold (2012) contends that students maintain a limited knowledge conception about models because they do not understand the role of models as being explanatory and predictive nature. Also, Treagust et al. (2002) claim that students do not understand the role of science models, model purposes, the limitations of science models, and especially those science models they encounter in their daily classes.

It has also been noted that science pre-service teachers understand that models are used to represent ideas, but they do not recognize how these models are used to make a prediction (Kenyon et al., 2011). These pre-service science teachers should be significantly focused while still in college, taking science courses and other teaching education courses at colleges (Schwartz & Skjold, 2012). This can be done by providing the pre-service science teachers with scientific models' instructions to introduce these instructions to the students when they are still young, and they will understand and get used to them as they advance academically. Studies such as Treagust et al. (2002) investigated primary school students' views on science models. The study yielded that knowledge of understanding of roles of models became better as students moved to higher grades, whereby students were able to tell the purpose of the scientific models.

Scientific Modeling

Scientific modeling is a scientific practice meant to prepare elementary and middle school science teachers by engaging students with authentic scientific inquiry when learning science (Davis et al., 2010). Scientific modeling is also described as Modeling-Centered Scientific, which is an "instructional approach in which learners engage in a scientific inquiry whose focus is on the creation, evaluation, and revision of scientific models that can be applied to the understand and predict the natural world" (Schwarz et al., 2009). The process of scientific modeling involves inquiry exclusively since a phenomenon is obtained from models with a theoretical focus on the structure (Upmeier, Driel, Kruger, 2019; Krell & Kruger, 2016; Stroupe & Windschitl, 2015). Scientific modeling has risen as an essential perspective for learners and teachers because it is used in all disciplines Upmeier et al., 2019). In addition, researchers have emphasized the use of scientific modeling (Lee, 2018) because scientific modeling is one of the scientific practices mentioned in the NGSS (the Lead NGSS, 2013; Windschitl, 2008), and scientists use models when inquiring (Skjold & Schwartz, 2012) to communicate their cognition when developing ideas (Cotterman, 2009). There are four steps involved in scientific modeling (Davis et al., 2010; Kenyon et al., 2011; Chiu & Lin, 2019), and the four steps of scientific modeling are construction, use of a model, evaluation, revising.

a) Constructing. This involves identifying the apparent features of a phenomenon and how those features relate to the other and their application in classrooms.
b) Using a model. This involves using the model to describe or explain a phenomenon and be able to predict it.
c) Evaluating- After using models to predict, students will determine the model
d) Revising- Revising refines the purpose of a model to do Scientific modeling plays a vital role in science education, and its creation and testing become an integral part of science learning and other disciplines.

The four steps of scientific modeling are founded on scientific inquiry. Therefore, creating a learning environment for students to practice modeling may produce students who are the experts in developing and evaluating the scientific knowledge and result in the subject matter expertise. Steps of scientific modeling are similar DEAR. Chiu & Lin

(2019) have proposed a model called DEAR cyclic, which is goal-oriented and creates a scaffolding of students. DEAR stands for Development, Elaboration, Application, and Reconstruction of a model (Chiu & Lin, 2019; Louca, Zacharia & Constantinou, 2011; Kenyon, et al., 2010). During the development phase of modeling, students engage themselves with the idea of describing, predicting, and explaining a phenomenon, and this will lead students to carry out an investigation of the model they have created and gather evidence and observation from the present experiences of the physical world (Louca et al., 2011).

Students involved with scientific modeling can make their thinking visible because scientific modeling enables them to test their conceptual framework (Ioannou & Angeli, 2015). Studies have also shown that students who understand the nature of scientific modeling learn better comparatively those who do not understand it (Lee, 2013) because when a complicated situation of scientific modeling is presented to those students who are knowledgeable about scientific modeling, it encourages them to engage with scientific practices (the NGSS Lead States, 2013; Gray & Klyve , 2018). It has also been noted that when students engage with scientific practices, they construct ideas through social construction among them, which fosters students' active learning (Oh, 2011; Singh & Yaduvanshi, 2015). Students' engagement will lead to the development of models and use of scientific modeling.

Also, students must understand the nature of models by engaging themselves with scientific modeling of different inquiry tasks (Oran-Bekiroglu & Arslan-Buyruk, 2014)). When students are involved in the argumentation during scientific modeling, it may lead them to engage in inquiry-based activities, which will enable them to tackle complex scientific concepts. The inquiry-based activities will lead students to scaffold. Such activities may also enable them to identify misconceptions in other students and be able to correct them.

However, engaging students with scientific modeling can be challenging since elementary and middle school teachers struggle with scientific modeling while teaching their content areas, limiting students' perception of the knowledge of scientific modeling (Davis et al., 2010). It has also been noted that the pre-service teachers have little experience with scientific modeling (Kenyon et al., 2011), and there are limited studies that engage the pre-service teachers with an inquiry about modeling (Oran-Bekiroglu & Arslan-Buyruk, 2014). However, with the help of designed instructions, pre-service teachers can develop a deeper understanding of scientific modeling which they can use in the preparation while creating their model-based lessons (Windschitl & Thompson, 2006). For instance, Zangori, Friedrichsen, Wuff, & Womack (2017) performed a study with 11 elementary and middle secondary school pre-service teachers, which explored how the pre-service teachers' models of the process of teaching and learning changed over time and the pre-service teachers' views on the value of modeling. The study revealed that the use of models enabled the pre-service elementary teachers to integrate modeling in their lessons plans which the pre-service teachers had seen to be challenging to comprehend initially. It was also found that modeling bridged the gap between teaching and learning, and at the same time, it enabled the pre-service teachers to reflect on their teaching practice among themselves.

Another study by Windschitl and Thompson (2006) focused on 21 pre-service teachers who engaged with the learning activities to understand the science models and how the models are used when performing an inquiry. The study conducted inquiries that were completed by students in which they developed a model to represent a natural phenomenon, tested the model and used the results from the model to revise the original model they had initially developed. The study resulted in the designed instructions helping the pre-service teachers to create the complexity of the scientific models, which led teachers to integrate model-based lessons in their classes. However, it was discovered that the pre-service teachers could not use theoretical models to develop their investigation. Hence, Science teachers need to know more about science to teach well (Kind, 2009). Model-based entails a lot, and pre-service teachers ought to learn about scientific modeling and be able to apply its purposes and at the same time guide students to the understanding of scientific modeling and how scientific models and modeling help in science understanding (Davis & Nelson, 2011). To acquire knowledge of scientific modeling, educators need a guided practice to engage the pre-service teachers (Schneider, 2012). One way of equipping the pre-service science teachers is to provide them with scientific modeling instruction. For instance, Cotterman (2009) study examined how pre-service teachers' elementary teachers develop teachers' knowledge of scientific modeling when they are given modeling-centered instructions in a science method course. It was found that the pre-service teachers improved on their understanding of using scientific models as undesirable when teaching to using them as a thinking tool to help students develop science content knowledge.

Additionally, the pre-service science teachers need to develop the ability to evaluate students' scientific models (Davis & Nelson, 2011). Davis & Nelson (2011) investigated the approaches and criteria pre-service teachers used to evaluate elementary students generated scientific models. It resulted in the pre-service teachers understanding the scientific model-based pedagogies, which led to their developed ways of assessing students' scientific models. Also, acquiring scientific modeling requires one to integrate different ideas of subject matter, science models and scientific modeling, learners, learning, and instruction to connect existing ideas about learners. (Davis, Nelson & Beyer, 2008).

Model-based Inquiry

Model-Based Inquiry (MBI) is a pedagogical approach to teaching that enables students to learn science through inquiry by engaging with scientific models according to that of scientists (the NGSS Lead States, 2013, p.14; Oh &Oh, 2010). MBI is designed for K-12 science instructions in which students engage themselves with meaningful scientific tasks which involve developing science models about an overarching phenomenon (Huang et al., 2018). MBI is likened to scientific inquiry because:

> All scientific disciplines are guided in their inquiries by models that scientists use to explain data and nature further; the development, use, assessment, and revision of models and detailed explanations play a central role in scientific inquiry and should be a prominent feature of students' science education (Campbell & Neilson, 2012).

National Science Education Standards (National Research Council, 1996; Alozie et al., 2010) defined scientific inquiry in education is defined as a variety of activities which involves observations; asking questions; research of information information to uncover what is already known and what is not known.

MBI is achieved by engaging students in small groups in which they are encouraged to practice modeling and develop and evaluate their models and provide evidence-based information about their models (Huang et al., 2014). MBI has received critical attention in every learning discipline (Passmore et al., 2009) due to its varied advantages. First, MBI refines students' knowledge of models and modeling, contributing to students developing and using models while learning (Lee, 2018; Xiang & Passmore, 2015). Second, MBI enables students to build and rebuild models for scientific investigation purposes (Campbell & Neilson, 2012). Third, MBI helps elevate students' deep learning in scientific practices (Carr et al., 2019). Forth, MBI engages students more deeply with the content and helps students develop authentic explanations in science classrooms (Gray & Klyve, 2018). Fifth, MBI encourages students to engage with the content, which involves three epistemic characteristics of scientific knowledge: revisable, explanatory, & generative (Windschitl et al., 2008). Sixth, MBI focuses on the main concerns in science education and the teaching of authentic scientific inquiry, which provides an instructional design to help students learn and understand science better (Baze, 2017). Finally, MBI develops a student's curiosity, and it does not engage in any prior knowledge or specific skills for students to have achievable results but present intelligence (Dass, Head & Rushton, 2015).

There are four stages of MBI (Windschitl et al., 2008; Park, Rodriguez Campbell et al., 2019; Windschitl, Thompson & Braaten, 2020). The first stage of MBI, Planning for Engagement with important Science Ideas, entails "doing the intellectually rigorous work of unpacking standards, identifying an anchoring phenomenon and driving questions, and pinpointing the important science ideas that students need to build a scientific explanation of the phenomenon. The second stage, Eliciting Students Ideas, is practiced in the classroom in which students are involved. In this stage of MBI, a phenomenon and a question behind it, when introduced, will evoke students' thoughts by reflecting on their experiences to help them produce an explanation concerning an aspect. The third stage, supporting students' On-Going Changes in Thinking, helps to "support on-going changes in thinking by providing learning experiences that help coordinate their ideas and powerful ideas in science to build a scientific explanation of the anchoring phenomena. “In the last stage, pressing for Evidence-Based Explanations involves asking students to provide authentic explanations with evidence. All these phases of MBI engage students with scientific modeling, developing a description by developing arguments; however, there is not much focus directed to post-secondary science education (Baze, Christina & Gray, 2018).

Another study that evaluated the instructional impact of MBI on the pre-service physics teachers' conceptual understanding of dynamics found that providing students with modeling activities that involve inquiry engaged students' conceptual learning (Buyruk & Bekiroglu, 2018). However, to successfully engage students to learn and understand MBI, there has to be an implementation of the development of highly qualified teachers (Windschitl et al., 2008). Therefore, MBI has to be focused on while pre-service teachers are still in college. For example, in a study done by Baze & Gray (2018), which focused on science in the introductory biology course for the community college student, these two researchers stated that MBI impacted the students, whereby the pre-service teachers gained skills in the development of their modeling.

Furthermore, another study evaluated the pre-service teachers' epistemologies of scientific models and model formation through MBI. The study reported that engaging the pre-service teachers through inquiry in model development; eased students reasoning on models, enabling them to understand models. Through MBI, students could develop their models and revise and expand evidence resulting in a phenomenon (Organ-Bekiroglu & Arslan-Buyruk, 2017).

Limitations of Scientific Modeling and MBI in Schools. Scientific modeling is not prioritized in elementary and middle school since they are used for illustrating and communicating (Kenyon et al., 2011). Therefore, the use of scientific modeling can be a challenging work (Campbell et al., 2012) because engaging students to create and use models has emerged recently as an essential science practice that needs to be used in the science classroom to enable students to develop knowledge (Park et al., 2019). As a result, the pre-service teachers are faced with challenges when it comes to their teaching, such as learning to engage their students with scientific practices (Kenyon et al., 2011).

For teachers to be effective in MBI, they need a clear understanding of the nature of scientific modeling (Windschitl et al., 2008). However, enacting MBI is facing challenges. First, teachers possess limited views about models and modeling, and when exposed to model-based teaching, they lack the vital information about modeling (Campbell & Neilson, 2012; Kenyon et al., 2011). Second, most teachers worldwide do not have enough experience with scientific modeling, which makes them possess little knowledge of their students' ideas about scientific practices (Schwarz, 2009). Third, a more significant number of teachers only understand that models are used when making visual aids to explain complex ideas or provide ways in which things work, but they hardly talk about how these models are essential when making predictions or used to gather the information that is not directly observed (Stoupe & Windschitl, 2015; Schwarz,2009). Fourth, the model is always not applied in the teaching practice. Models are only used when the teacher needs to make an illustration; teachers are limited in the understanding of the importance of models to meet the needs of scientific teaching and learning; teachers do not have experience in modeling and therefore lack the expertise; teachers do not have enough experience in the understanding of the models and their functions to help students to acquire the knowledge of models construction, their use and the way they are applied in science (Lorao (2019).

Also, new teachers, especially those who hold degrees in science, have a shallow understanding of authentic forms of inquiry (Windschitl, 2006), and this limits their conception of the role of models in the scientific work and makes it difficult for them to engage students in the ambitious reform-based pedagogies (Windschitl et al., 2014). Because scientific modeling requires a lot from teachers, it makes scientific modeling rarely talked about in class (Kenyon et al., 2011). Due to these limitations surrounding teachers, there is a great need to support pre-service science teachers with the knowledge of modeling if we consider modeling to be important in classes (Lorao et al., 2019). The literature about scientific modeling and Model-based Inquiry provided ideas about designing a scientific modeling activity for the preservice teachers and how it could be administered. The scientific modeling activity contained the three steps and the four stages of Model-based Inquiry that guided the study. Also, the interview questions were designed from the three steps of scientific modeling and the four stages of Model-based

Inquiry. Additionally, an assignment was designed for the preservice to demonstrate their teaching ideas in classrooms.

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Summary

The literature about scientific modeling and Model-based Inquiry provided ideas about designing a scientific modeling activity for the preservice teachers and how it could be administered. The scientific modeling activity contained the three steps and the four stages of Model-based Inquiry that guided the study. Also, the interview questions were designed from the three steps of scientific modeling and the four stages of Model-based Inquiry. Additionally, an assignment was designed for the preservice to demonstrate their teaching ideas in classrooms.

Chapter 3

Methods

This chapter identified the target sample of participants and designed the 11 interview questions, which were completed at the beginning and end of the scientific modeling activity. Also, the teaching assignment was completed by the participants at the end of the scientific modeling activity. This chapter also focused on developing a framework that contained codes, subcode identification, and the description of what the teacher knows about scientific modeling. Additionally, the site of data collection and analysis was determined.

In the literature, scientific modeling has been defined, its involvement projected, and its enactment focused on science teachers in the classroom. However, literature has also provided evidence that preservice teachers rarely incorporate scientific modeling in their classes because they do not understand it. For example, a study by Schwartz & Skjold (2012) described the preservice teachers' conception of scientific models before and after a science course using multiple models and explicit instructions about models and modeling. The study confirmed that teachers possess a limited concept of models because they do not understand the role of models as explanatory and predictive. Another study by Cotterman (2009) examined how preservice elementary teachers develop PCK for scientific modeling when given modeling-centered instruction in a science methods course. The study reported that preservice teachers made little pedagogical gains from using models as static products and thinking tools for students to develop science content knowledge. In these two studies, my interest escalated in exploring scientific modeling and contributing to the literature by providing insight into the teachers' understanding of scientific modeling in natural science and its application in the classroom setting.

Therefore, the purpose of this study was to explore what the graduate science preservice teachers know about scientific modeling and what they know about Model-based Inquiry during a course on the methods of teaching science. A qualitative case study research was designed to address this purpose to answer my two overarching research questions.

1. What do the University of Toledo (UT) graduate preservice science teachers know about scientific modeling during the methods of teaching science courses?
    a. What do UT graduate preservice science teachers know about scientific modeling at the beginning of the scientific modeling activity?
    b. What do UT graduate science preservice teachers know about scientific modeling at the end of the scientific modeling activity?
    c. How does UT graduate science preservice teachers understand of scientific modeling change at the end of scientific modeling activity?
2. What do UT graduate science preservice teachers know about Model-based Inquiry during the methods of teaching science course?
    a. What do UT graduate science preservice teachers know about Model-based Inquiry at the beginning of modeling activity?
    b. What do UT graduate science preservice teachers know about Model-based Inquiry at the end of the activity?
    c. How do UT graduate science preservice teachers understand Model-based Inquiry change at the end of scientific modeling activity?

d. How do UT graduate science preservice teachers understand scientific modeling activity and the assignment change at the end of scientific modeling activity?

Research Design Approach

This study involved a qualitative research method design case study. Qualitative research is a form of inquiry whose intent is to analyze the information which informs of language and behavior, all of which occur in a natural setting. Qualitative research is characterized by data generated from grounded human experience (Nowell et al., 2017). Those who engage in qualitative research methods engage in a naturalistic inquiry and real-world settings to develop a rich narrative description (Patton, 2005). A qualitative study has been described by Maxwell (2012) as "do-it-yourself rather than an off-the-shelf process one that involves tackling back and forth between different components, assessing their implication for one another." A qualitative research study is also flexible, inductive and it does not engage in a specific and strict protocol (Maxwell, 2012), unlike quantitative research methods, which are essential for deductive approaches in which "a theory or hypothesis justifies the variables, the purpose statement, and the direction of the narrowly defined research questions" (Borrego, Douglas & Amelink, 2009). Case study research provides information regarding a social phenomenon in real life (Dutton, 2013). Also, it provides rich, detailed explored information about issues that occur in real life (Cresswell et al., 2011), which may lead to hunting for solutions to curb such problems or develop ways to minimize such problems as teachers' inability to comprehend the understanding of scientific models and its application in the classroom.

This research study involved an exploratory single qualitative case study in providing in-depth, multifaceted ideas about the complex issues in science preservice teachers about scientific modeling and Model-based Inquiry. The study involved what graduate science preservice teachers know about scientific modeling and Model-based Inquiry in methods of teaching science courses. This case encompassed a detailed examination of scientific modeling in the context of science preservice teachers learning in teaching science methods to obtain concrete, in-depth contextual knowledge on scientific modeling.

Therefore, this study focused on two interviews and the collection of one assignment, which required the participants to answer scientific modeling questions and describe how they would teach a scientific modeling class representing a phenomenon. Eleven interview questions were developed from understanding and teaching scientific modeling to answer the two research questions. The interview questions were categorized into two, in which questions one through six required the participants to demonstrate their knowledge of scientific modeling, and questions seven through eleven required the participants to demonstrate their understanding of Model-based Inquiry.

Study Setting, Recruitment, Sampling, Demographic, and Course Setting

The study took place at the University of Toledo in the Spring Semester of 2021, and the study engaged in a Convenient Sampling Method because the researcher was a student at the University of Toledo. Also, the study took place in Methods of Teaching Science course. Methods of Teaching Science is a graduate-level course that provides the initial study of methods and the materials required to teach and learn science in the middle and secondary classroom. This course also emphasizes planning, content standards, and instructional strategies students need. The emphasis on teaching Science Methods made the course preferred for data collection. During the Methods of Teaching science course, the class met online through The University of Toledo WebEx on Wednesdays and Fridays for fourteen weeks, and each meeting took three hours from 11:30 am-2 pm every day of the meeting.

Six graduate science preservice teachers registered for the Methods of Teaching Science course, and four white male and a white female preservice teacher signed the consent forms and completed the first interview. Two males and a female completed the study, while two males did not. Out of the two who did not complete the study, one completed two interviews but did not complete the assignments, while one participant only completed the first interview. The participants in this study were future secondary school science teachers and middle school science teachers. Table 1. Will describe the participants' gender, pseudonyms given to participants, their subject matter, and the data collected.

Table 1

Description of participants who took part in this study

Pseudonyms	Gender	Subject matter and grade level	Interview One	Interview Two	Assignment
Simba	Female	Secondary school science	Yes	Yes	Yes
Nyati	Male	Secondary school science	Yes	Yes	Yes
			Yes	Yes	Yes
Swara	Male	Middle-grade science	Yes	Yes	No

Sungura	Male	Middle-grade science	Yes	No	No

Procedures for the Open-ended Interview Questions.

The participants completed the same interview questions at the beginning and end of the scientific modeling activity. Each interview took approximately one hour**.** The open-ended interview questions were designed to answer my two research questions. The interview questions were categorized into two, in which questions one through six required the participants to demonstrate their knowledge of scientific modeling, and questions seven through eleven required the participants to demonstrate their knowledge of Model-based Inquiry. The two interviews were virtually completed via the University of Toledo WebEx at the participant's convenient time following these questions:

1. What experience have you had about creating and using scientific models?
2. What can be done with scientific models?
3. What are some of the scientific models' features?
4. What are the scientific model features used for?
5. What experiences have you had with the steps of scientific modeling?
6. What can be done with the steps of scientific modeling?
7. How would you engage students in a scientific modeling class?
8. What instructional strategies might you use when teaching scientific modeling classes?
9. How would you assess your students' understanding of scientific modeling?
10. What do you think might influence students' thinking about scientific modeling?

11. Would you teach one lesson using different scientific models? Why or why not?

Procedure for the Assignment

The Methods of Teaching Science course instructor posted the scientific modeling and Model-based Inquiry assignment on the University online course site, blackboard, and the participants obtained them. The instructor also posted the instructions for the assignment, which required the participants to demonstrate the knowledge of scientific modeling that they would incorporate in their class while teaching their content areas. The researcher also read the assignment's instructions before the participants began their assignments. The following are instructions for the assignment, including the seven questions the participants answered in the assignment.

Awareness of Modeling in the Science Learning Environment

Answer each question with several sentences to a paragraph-length answer. Complete sentences, please, and please give me enough background information to visualize the unit/lesson when the model was used. Please return to me when completed by email. You can talk with your mentor teacher about this assignment.

1. What is the topic of the science unit you are reporting on here, and what is the key concept or set of concepts intended to be taught by using the model?
2. What is the superordinate scientific theory related to the model? (For example, if you modeled evolution by having students collect different colored dry beans in the grass outside the classroom, the science concept would be "natural selection" (see Question 1 above), and the scientific theory would be "evolution.")

3. How good of a fit is this model for teaching this concept? (In other words, you may have taught this model and then found out that there are better modeling activities. Alternatively, you may want to make an argument that this is a good fit. Either way, use logical reasons to support your claim.)
4. How does using this model benefit students? Does it increase motivation and understanding and make the concept easier to grasp? (Support your answer with logical reasons.)
5. What are the potential dangers of using this model in the classroom? (These dangers might be physical if the materials involved are toxic, for example, but the dangers are cognitive. In other words, the use of the model can mislead students in some way. Identify 1-3 dangers and support your answer with why they are dangers.)
6. Is the model a physical model or conceptual? If physical, is it a scale model or relational? If conceptual, is it a kind of flow chart, or does it present a set of ideas/relationships like a table or graph?
7. Overall, how well did the use of this model work with the students? What is your evidence for its effectiveness or relative lack thereof? Would you use this model again or try a different way to model the concept(s)?

Data Collection

Data collection included two interviews which were conducted individually. The interviews were video recorded at the beginning and the end of the semester. In addition, textual data was collected from the written responses to the assignments at the end of the semester. The study involved data collection during the 2nd and the 14th weeks of the spring semester, 2021. Interview data were collected in the 2nd and the 14th week of the spring semester, in which each participant was interviewed with open-ended questions, which were completed individually on a scientific modeling knowledge based and Model-based Inquiry. Also, participants submitted the assignment on the 14th week on scientific modeling and submitted it to the researcher. A sample of the assignment titled "the awareness of Modeling in the Science Learning Environment" was collected from each of the three participants is represented below.

Awareness of Modeling in the Science Learning Environment Assignment

Answer each question with several sentences to a paragraph-length answer. Complete sentences, please, and please give me enough background information to visualize the unit/lesson when the model was used. Please return to me when completed by email. You can talk with your mentor teacher about this assignment.

1. What is the topic of the science unit you are reporting on here, and what is the key concept or set of concepts that are intended to be taught by using the model**?**

   The topic we are covering in class this week is meiosis. We have already covered mitosis and used several graphical representations to understand how chromosomes move through mitosis. We have also discussed cytokinesis in plant and animal cells, and how they are different. We have identified mitotic cells as genetically identical to the parent cell, and meiotic cells provide genetic diversity through some key developments. The key concept we are focusing on in meiosis using modeling today is "crossing over" as it occurs in prophase 1.

2. What is the superordinate scientific theory that is related to the model? (For example, if you modeled evolution by having students collect different colored dry beans in the

grass outside the classroom, the science concept would be "natural selection" (see Question 1 above) and the scientific theory would be "evolution.").

The concept is meiosis, specifically the process of crossing over in meiosis. This is subordinate to the theory of evolution. Evolution is the superordinate theory as evolution relies on genetic variation at the level of the organism.

Data Preparation

To prepare the collected interview data about what the preservice teachers know about scientific modeling and what they know about Model-based Inquiry for analysis. The interviews videos were transcribed into data texts using the Otter online application. The transcripts were organized into four columns with the interview questions in the first column, participants in the second column, interview one data transcripts in the third column, and interview two data transcripts in the fourth column. In addition, the written responses to the assignments of the three participants were read, and they were used to compare the two individual interview responses on their knowledge of Model-based Inquiry since the assignment was completed since the assignment required them to design and explain how they could teach scientific modeling in their classes. A sample for the three participants' transcripts is provided in table 2.

Table 2

Provides a Sample transcript for Simba, Nyati, and Chui

Interview questions	Participants	Interview one data transcripts	Interview two data transcripts
Q7. How would you engage students and assign modeling class?	Simba	Since we have just really talked about them like, you can use models in your classroom. Is most of our discussion on them to do what to teach, teach, and demonstrate abstract or the little broad or very minute or much bigger concepts. So, what I have been doing with remote learning is as we break down the pieces, asking students what they know about things ahead of time, so like what do you think of when you think of DNA? What does that mean to you? What are the letters stand for just like a broad, like, anything they say will be corrected? Because we do not know anything yet. And then that opens them up to the idea of engaging with me because they know I am not doing like you are right, or you are the wrong type of thing. And then, as we go through like the pieces, like today, we talked about the different enzymes, and we just defined them with little names. So, like helicase is the unzipper, and polymerase proofreads, among other things. So then later, once they had those definitions and	So, engaging students, my students are already hands-on, like they really prefer having things that they can see or manipulate or pass around. So, the engagement part is pretty easy with modeling. I think the biggest thing is making sure that when I'm engaging students, they have an understanding of what the point of what we're doing is so like, if they come into class, and there are just beads and pipe cleaners on the desk before I started class, or before I've explained what they're going to be used for, then they are just doing like arts and crafts time. So, when I am engaging students, I think it's essential for there to be one an expectation of what the modeling will be used for. Moreover, even though it's beans, pipe cleaners, or beads, it's still, we're in science class. So, we still have to use these tools for science. So, one is just setting a precedent of like focus and like really getting the most out of the modeling that we're doing. However, then I think it's also a really good way to incorporate differentiation with students. because on one hand, if I have students that are really struggling with a concept, they can use the model to support getting just the comprehension. So, I can give them like

Interview questions	Participants	Interview one data transcripts	Interview two data transcripts
		the pieces, we built on that by putting some of the pieces together. So now, like, what does it mean? If something is not proofread correctly? What does that mean for the bigger picture? So, I try to give the pieces. And then as we expand and have the model working together to get them doing more critical thinking or cause and effect or predictive questioning outside of just, like telling me what I think does?	simple problems, they can use the model to start integrating that problem solving on their own. But when I have students who are kind of advanced and ready to move on, I can give them a more complex problem. And they can use the model in the same way but more application and then, like the creativity part of learning.
	Nyati	um, at least in a, in a perfect scenario, how I like to approach class, especially a science class is a lot of hands-on learning. So, if you're able to kind of create like a hands-on lab by introducing, for example, like observations to hypothesis, and they're able to critically think about what they're learning about, I think that would be a perfect example of scientific modeling class.	I think one of the big things is creating a curriculum that they there's multiple instructional strategies. Also, where it's not just where they have to learn memorization, it's the application of concepts I think is so important, it makes it easier for them to understand. But especially when you're manipulating different variables. But especially when you're manipulating different variables within an example or things like that, like it gives the students an opportunity to think a little bit harder about what they're learning about, but also kind of add a little fun to it. And I think one thing that I'm I really like doing is finding those real-world examples. So that way, not only do students will be able to apply the concepts that they need to know. But they're also learning about stuff on the outside world that they in just a typical classroom when you're looking at memorization, they may not get that access to. So, I think

Interview questions	Participants	Interview one data transcripts	Interview two data transcripts
			engaging is also using some of those real-world applications into, like biology, education, or even science education.
	Chui	Well, physics, um, I would say I'm pretty, it's I'm pretty lucky, it's pretty easy. To model, there's a lot of demonstrations you can do. So, we're talking about sound right now. So, we can talk about tuning forks. And, you know, if we hit this frequency with this frequency, what's changing? We can use different models as in Okay, here's the same frequency but through a different medium. You know, why is that? Why does that change? But the biggest thing I think, in science class is a lab. A lab is modeling a relationship, whether it's organic chemistry versus physics or, you know, anatomy, right? I dissected an eyeball and anatomy class. Well, that's a model, whether it's plastic or real. It's still showing me it's modeling the body parts as modeling the anatomy. So, I think, as a science teacher, your biggest thing is to just let kids explore using models within a lab setting. Kids are naturally inquisitive, they're curious, they're exploratory. They like to explore things, so I don't feel like you have to try super hard in a science setting, I think if you just give	So yeah, scientific modeling, I think that when people teach science, they don't think of teaching this. But I think you could really help your students subconsciously think of modeling such as well. This is a model because it's showing a relationship. And if they think of it, you know, an equation as a model, or, you know, something, a demonstration that you're showing, this is a model, a model of a concept, a model of a situation, or scenario, a model of a relationship between things. And I think if students can think of them in that terms, and might help them, break it down and be able to, in the future, break down things on their own. And think of how you could model the relationship or model a concept that maybe the teacher does not provide a model for.

Interview questions	Participants	Interview one data transcripts	Interview two data transcripts
		kids a good question and say, Okay, now I want you to think about it, use this stuff and explain what explain your answer. I think kids naturally want to explore those type of moments.	

Data Analysis Preparation

Modeling descriptions were used to develop a framework for analyzing data. Oh & Oh (2011) argued that science teachers need to know the nature of models, their purpose, and their uses in the science classroom. Also, learning to model is embedded in teacher education science courses Chittleborough & Treagust, 2009). Therefore, to answer my first research question, the nature of models was identified and listed down according to (Windschitl et al. 2018; NGSS the Lead 2013) stated the nature of models.

Nature of Models

The nature of models enables scientists to identify and understand the world's patterns to provide scientifically scientific-based explanations and predict them. The following are the nature of models. The nature of models was used to develop codes.

1. Scientific models must signify a phenomenon.
2. Scientific models should contain detailed information about a specific event under certain conditions.
3. Scientific models should enable students to visualize what is written on a paper and connect what is modeled.
4. Scientific models entail both those features that can be seen and those that are not seen.
5. Scientific models should meet the quality of reversibility in that all the processes involved should be tested and show the relationships between them.
6. Scientific models may not mean the whole world precisely because other features might be observable while others might be uncertain. Therefore, it is imperative to understand how each model is represented and how it works.

7. Models are full of approximation and assumptions, and therefore students must keep working on their models as they refine those.

Also, the purpose of modeling was identified and listed down according to Oh & Oh (2011).

Purpose of Modeling

The purpose of models was used to describe and predict the behavior of scientific phenomena; they were used to develop codes. The following are the purposes of models used in this study.

1. Models are used to explain the features of a phenomenon (Campbell et al., 2019).
2. Science models are used to develop questions and explanations to generate data that can be used to make predictions and communicate ideas to others (NGSS the Lead, 2013).
3. Models are used when making an inquiry which yields models when performing an investigation (Skjold & Schwartz, 2012).
4. Models aid in explaining a phenomenon which leads to new knowledge production (Kenyon et al., 2011).
5. Finally, models provide a view of how things work and make predictions (Lee, 2018).

Additionally, the knowledge associated with modeling was identified and listed since learning about modeling is embedded in science courses in teacher education courses (Chittleborough & Treagust, 2009). Scientific modeling is a scientific practice meant to prepare elementary and middle school science teachers by engaging students with authentic scientific inquiry when learning science (Davis et al., 2010). There are four steps of scientific modeling: constructing, evaluating, and revising (Kenyon et al., 2010). The process of scientific modeling is represented in the following four steps

Steps of Scientific Modeling

Steps of scientific modeling are the processes involved, from identifying the suitable model and designing and achieving its purposes according to scientific knowledge. These steps of scientific modeling were used to develop codes, and they are listed below.

a) Constructing involves identifying the apparent features and how those features relate to the other and their application in classrooms.

b) Using-involves the used model to describe or explain a phenomenon and be able to predict it.

c) Evaluating- After using models to predict, students will determine the model meets the need.

d) Revising- Revising refines the purpose of a model to do Scientific modeling plays a vital role in science education, and its creation and testing become an integral part of science learning and other disciplines.

Further, to gain a better insight about what the graduate science preservice teachers know about the general understanding of scientific modeling, a codebook with the nature of models, the purpose of modeling, and the process of modeling was designed using the four steps about the knowledge of scientific modeling was developed from the works of literature on four steps of scientific modeling (Davis et al., 2010; Kenyon et al., 2011; Chiu & Lin, 2019). This nature of models, the purpose of modeling embedded in the process of modeling developed with the four steps of modeling. The four steps of scientific modeling were evaluated and simplified into three codes in which using a model and the nature of models were embedded in the evaluating step of scientific modeling and were categorized as subcodes. The description of codes was designed from the logical understanding of scientific knowledge of modeling. Table 3 describes a codebook with the possible types of codes, subcodes, and codes descriptions that teachers were expected to demonstrate about their understanding of the nature of models, the purpose of models, and the modeling process to answer the first research question. The codebook was prepared and tabulated to help answer the first research question.

Table 3

Describes the General understanding of Scientific Modeling Codebook

Codes	Subcodes	Description of codes
Construct	Knowledge of adapting a model recreating models	Models are built from existing models
Evaluate	Features of models	Some model features may not be visible. Models show the interaction between different parts of a phenomenon Models are manipulable Models are specific Model features explain an event in detail. Models' features are used to make a prediction Models signify a phenomenon
	Using	Models are used for demonstration Models are used for comprehension Models are used as the existing knowledge Models are used to solve a problem

Codes	Subcodes	Description of codes
		Models are used to make comparisons and contrasts Models are used to ask questions Models introduce a concept

Scientific Inquiry

According to scientists, teachers need to know Model-Based Inquiry **(**MBI), a pedagogical approach to teaching through inquiry by engaging students with scientific models (the NGSS Lead States, 2013, p.14; Oh & Oh, 2010). To explore what teachers know about Model-based Inquiry, "scientific inquiry" was identified as the main code from the literature. The National Education Standards (National Research Council, 1996; Alozie et al., 2010) defined scientific inquiry in education as "a multifaceted activity that involves making observations; posing questions; examining books and other resources of information to see what is already known; planning investigations; reviewing what is known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results." The scientific inquiry code was identified from the literature that housed the four phases of Model-Based-Inquiry (MBI), categorized as subcodes. MBI is a pedagogical approach to teaching that enables students to learn science through inquiry by engaging with scientific models according to that of scientists (the NGSS Lead States, 2013, p.14; Oh &Oh, 2010). There are four phases of MBI (Windschitl et al., 2008 Park et al., 2017; Campbell et al., 2019; Ambitious Science Teaching, 2015).

The Four Stages of MBI

The phases of MBI are scientific inquiry-based used to engage students to ensure that they understand and use inquiry while learning and answering scientific questions.

1. Planning for engagement with essential Science Ideas
2. Eliciting Students Ideas
3. Supporting students On-Going Changes in Thinking
4. Pressing for Evidence-Based Explanations involves pressing students to provide authentic explanations with evidence.

These four phases of MBI were revised and refined into four sub-codes to capture a wide range of understanding what the teachers might know important while teaching a scientific modeling class. The description of code, the scientific inquiry was designed from the logical understanding of scientific inquiry. Finally, the codebook was prepared and tabulated to help answer the second research question, as described in table 4.

Table 4

Teachers' Knowledge of Model-based Inquiry Preparation Codebook

Codes	Subcodes	Description of Codes
Inquiry	Teacher planning engagement for students	The teacher develops anchoring event Teacher develops hypothesis The teacher plans what model to teach in class Teacher plans for thinking time and interaction with the model
	Teacher and students eliciting students' ideas	The teacher asks students to build a model The teacher introduces a new model The teacher uses different strategies describing a model Models are manipulable The teacher identifies a misconception in a model The teacher describes the specificity of a model The teacher manipulates a model to activate students' thinking The teacher uses models to describe its relationships with the phenomenon The teacher uses models to design a study The teacher uses models as the existing knowledge The teacher introduces a phenomenon The teacher describes the modeling The teacher uses models for comparisons The teacher builds a model The teacher introduces different models in the class The teacher uses models to ask open-ended questions The teacher allows students to explore a model The teacher introduces a model to encourage critical thinking The teacher encourages students' manipulation of models The teacher uses a model to ask questions about a phenomenon

Codes	Subcodes	Description of Codes
	Teacher and students supporting students' ongoing changes in thinking and analyzing ideas	The teacher describes the specificity of a model The teacher presents different model types such as videos, simulations, and diagrams to relate to a phenomenon. The teacher presents different model types such as videos, simulations, and diagrams to relate to a phenomenon. The teacher introduces a model to encourage critical thinking The teacher builds a model for class The teacher asks students to build a model The teacher describes a model The teacher uses models to describe its relationships with the phenomenon Students use models to ask their teacher questions The teacher uses the model to study the phenomenon The teacher describes the modeling The teacher introduces a model to encourage discourse The teacher uses a model to engage students in discussion groups The teacher uses the model to encourage students-project based The teacher and students analyze modeling The teacher uses models as an assessment tool The teacher uses models as the existing knowledge The teacher uses the model to ask open-ended questions The teacher allows students to explore a model The teacher encourages students to relate the model with a phenomenon Teacher and students identify a misconception in a model The teacher encourages students' manipulation of models The teacher encourages critical thinking Students develop their questions about modeling

Codes	Subcodes	Description of Codes
	Teacher and Students Pressing for evidence-based explanations	Teacher encourages scaffolding The teacher uses the model to ask open-ended questions The teacher introduces a model to encourage critical thinking The teacher uses models as an assessment tool Students describe a model The teacher identifies a misconception in a model

Data Analysis

The two interview videos were transcribed into texts data using the Otter online application. To answer my two research questions, the texts data were read and re-read several times to identify the information closely related to four codes: Inquiry, Construct, Evaluate, and Revise. Also, the data texts were re-read to specify their respective subcodes and the description of codes. A descriptive coding method was used to identify the codes from the text data. Descriptive coding enables the researcher to group the ideas presented by different participants (Saldana, 2017), allowing the researcher to capture how the participants' opinions differ. After identifying codes, a claim of what teachers know about scientific modeling was made and was categorized under each of their respective columns to match the codes, subcodes, description of codes, and a claim of what the teacher knows. An example is listed in table 5.

Table 5

Description of Codes, Subcodes, description of codes of Simba' before the Scientific Modeling activity

Raw data	Code	Subcodes	Description of codes	What teacher knows
Q1, we did this with the vespers model with balls and connectors for the bonds. Balls represent atoms and then bond with sticks making molecules.	Inquiry	Teacher eliciting students' ideas	Teacher using models are used to represent a phenomenon.	The teacher knows that vespers models can be built to represent atoms and molecules.
Q1, we do a lot within like life science biology, looking at cells and cell structure, looking at plant cell structure compared to animal cell.	Inquiry	Teacher eliciting students' ideas	Teacher using models to make comparisons and contrasts	The teacher knows that models are used to compare and contrast plant cells and animal cells.
Q1, we are doing modeling this week with the DNA structure we're getting into, like how the DNA model from Watson and Crick was put together and how we can use that to understand the different	Inquiry	Teacher eliciting students' ideas	Teacher using the existing knowledge	The teacher knows that the existing DNA knowledge is used to study DNA parts

Raw data	Code	Subcodes	Description of codes	What teacher knows
parts of DNA replication.				

Table 6

Sample Transcript Analysis for three Participants

Participants names	Interview types	Raw data from Question 2	Codes	Subcodes	Description of the identified Codes	What the teacher knows
Simba	One	Like vesper's models, there is an online it is like a fat lab for vespers models, and as they add more electron groups, the digital model will respond and change its orientation.	Inquiry	Teacher eliciting students' ideas	The teacher introduces the model to activate students thinking	The teachers knows that online vespers mode ls can be introduced to activate students' thinking
	Two	I think that they are a more accessible, like point to learning for a lot of my like visual and tactile learners	Inquiry	Teacher eliciting students' ideas	The teacher introduces phenomenon	The teacher knows that models can be more accessible by visual and tactile learners
Nyati	One	With a simulation, for example, they're able to actually see it and come to life.	Inquiry	Teacher eliciting students' ideas	Models are used to describes relationships	The teacher knows that models can be used to bring things to life.

Participants names	Interview types	Raw data from Question 2	Codes	Subcodes	Description of the identified Codes	What the teacher knows
	Two	What I've been focusing on a lot now is applying, like real world applications, like if you're learning about another thing that I like to use, the example of, especially in biology is like. DNA will be turned into RNA, which will then be translated or transcribed into RNA, and then RNA will be translated into proteins.	Inquiry	Teacher eliciting students' ideas	The teacher uses the existing knowledge of DNA	The teacher knows that the existing knowledge can be used to explain DNA transcription to RNA and RNA translation to proteins
Chui	One	I would even go so far as like a model could be described as a lab, right	Inquiry	Teacher eliciting students' ideas	The teacher describes a model	The teacher knows that a model could be described as a lab
	Two	But that shows them that there is a reason that when they go to the store and buy sunglasses, some are polarized and some or not or how you know, things	Inquiry	Teacher eliciting students' ideas	The teacher knows that models are used to relate ideas	The teacher knows that polarized and unpolarized sunglasses can be used to understand the reason why

Participants names	Interview types	Raw data from Question 2	Codes	Subcodes	Description of the identified Codes	What the teacher knows
		like that happen or why we can wear contacts and networks or glasses and networks.				people wear contacts and networks or glasses and networks.

After the identification of codes, scrutinizing of codes for the title of themes were accomplished using thematic analysis method. Thematic Analysis is “a method of identifying, analyzing, organizing, describing, and reporting themes found within a data set” (Nowell, Norris & White, 2017). Themes were formed from the identification of the vital information was identified related to the study questions which was based on the analysis of repeated words and key terms.

Validity Threats

Since the participants attended the Methods of Teaching Science course and the interviews at their convenient time, there could be a possibility that those who completed the interview first might have shared the interview questions with those who had not, and their responses could not reflect the actual expected results, and that could affect the data. Furthermore, some participants would not have concentrated on answering the interview questions since there was no grade awarded or reward at the study's end. Therefore, the researcher identified a strategy to evaluate and deal with these threats by analyzing the participants' responses and comparing them with their assignment responses to enhance the stability of the study.

Also, two graduate students were invited to uncover errors, biasness, and to improve the quality of my research by assessing the participants’ summaries, codes, subcodes, description of codes, drawing the final claim about teachers know on scientific modeling and the assignments and themes, the researcher.

Permission and Ethics for Data Collection

The Dean School of Judith Herb College of Education was contacted and requested official permission to allow the researcher to collect data in the department.

The chairperson was also contacted, and the professor who offered the Methods of Teaching science course is also called, and which they all acted as gatekeepers to grant permission to allow the researcher to collect data.

Also, the researcher obtained permission from (http://www.utoledo.edu/research/RC/HumanSubs/) since the study dealt with human subjects. Also, the researcher completed the University's Collaborative Institutional Training Initiative (CITI) as a requirement for researching human subjects since the study involved human subjects of the graduate preservice science teachers.

Anonymity and Confidentiality

The graduate preservice science teachers were informed of the scientific modeling activity, and they were given time to decide to volunteer by signing a consent form. Furthermore, preservice science teachers were also informed of data collection and were assured of their confidentiality by reporting the data using codes to avoid any kind of embarrassment during data reporting since their real names were not used. Also, the graduate science preservice teachers were informed of the potential benefits to them if they chose to participate in the study since the scientific modeling questions and assignment would prepare them for the next level of being teachers after college since they would gain the scientific modeling and Model-based Inquiry knowledge which is one of the scientific practices stated in the *NGSS* and *K-12 Framework* as a requirement for each teacher (NGSS the Lead, 2013).

Summary

This chapter provides the methods involved with data collection and data analysis. In addition, this chapter describes the sample, the sampling method, the demographic of the participants, the study settings, and the questions answered in the study. Additionally, this chapter describes the permission from the University of Toledo to collect data.

Chapter 4

Findings

This chapter will focus on data analysis by identifying the codes and subcodes of scientific modeling, one code of Model-based inquiry, and four subcodes with the emerging themes. Additionally, the participant's summaries were written and compared, and the individual summaries of the knowledge of MBI was compared with the teaching assignments.

Scientific modeling is a scientific practice meant to prepare elementary and middle school science teachers by engaging students with authentic scientific inquiry (Hug, Kenyon,Teo, nelson, Cotterman & Davis 2008). Scientific modeling is also Modeling-Centered Scientific that engages students with a scientific inquiry to create, evaluate, and revise scientific models that can be applied to understand and predict the natural world (Schwarz, 2009)**.** This study studied scientific modeling to understand the teachers' understanding of scientific modeling and Model-based Inquiry. Additionally, participants were asked to describe their experiences with scientific modeling and teaching scientific modeling.

This exploratory study completed two interviews and one assignment. Interview one was conducted at the beginning of the semester before introducing the scientific modeling activity, and interview two at the end of the semester after introducing the scientific modeling activity. The assignment was completed at the end of the semester. Initially, five participants agreed to participate, but only three completed the study. This study was affected by the attrition of two participants whose data were not included at the end of this reporting. One only completed the first interview and did not complete the second interview and the assignment. The second participant completed the two interviews but did not complete the assignment. Finally, this section will compare the participants' knowledge of Model-based Inquiry of the two interviews and the assignments.

Two types of data analysis guided this study: the interviews and the assignments described to clarify this reporting. Table 7. below contains the participants' pseudonyms and the type of data collected.

Table 7

Description of Participants who took Part in this Study

Pseudonyms	Gender	Subject matter and grade level	Interview One	Interview Two	Assignment
Simba	Female	Secondary school science	Yes	Yes	Yes
Nyati	Male	Secondary school science	Yes	Yes	Yes
Chui	Male	Secondary school science	Yes	Yes	Yes
Swara	Male	Middle-grade science	Yes	Yes	No
Sungura	Male	Middle-grade science	Yes	No	No

Participants' Knowledge of Scientific Modeling before and After the Introduction of Scientific Modeling Activity

This section will describe the summaries of the participants' Knowledge of scientific modeling and the Knowledge of Model-based Inquiry before and after introducing the scientific modeling activity. Both interviews one and two had the same eleven questions. In questions one through six of interview one, the data were collected on participants' knowledge base of scientific modeling. Also, in questions seven through eleven of interview one, the data was collected on the teachers' knowledge base of Model-based Inquiry. Additionally, in questions one through six of the interviews two, the data were collected on participants' knowledge of scientific modeling after the introduction of scientific modeling. Also, also in questions seven through eleven of interview two, the data was collected on the teachers' knowledge base of Model-based Inquiry after the introduction of scientific modeling. During both interviews, the participants were asked to share their experiences with scientific modeling by giving examples where possible.

Also, questions one to six of the interview were developed to answer parts one, two, and three of the first research question 1.a. What do UT graduate preservice science teachers know about scientific modeling at the beginning of the scientific modeling activity. 1. b. What do UT graduate science preservice teachers know about scientific modeling at the end of the scientific modeling activity? 1. c. How do UT graduate science preservice teachers understand scientific modeling change at the end of scientific modeling activity?

Also, in both interviews, questions seven to eleven were developed to answer parts one, two, three, and four of the second research question. 2. a. What do UT graduate science preservice teachers know about Model-based Inquiry at the beginning of the modeling activity? 2. b. What do UT graduate preservice science teachers know about Model-based Inquiry at the end of the activity? 2. c. How do UT graduate science preservice teachers understanding of Model-based Inquiry change at the end of scientific modeling activity? 2. d. How do UT graduate science preservice teachers understand about Model-based Inquiry and the assignment change at the end of the scientific modeling activity?

Summaries of the Participants' Knowledge of Scientific Modeling before the Introduction of the Scientific Modeling Activity

Experiences in Creating and Using Scientific Models. All the participants portrayed their experiences of creating and using scientific models. However, Simba portrayed a better knowledge of scientific modeling than Chui and Nyati. For example, Simba included the knowledge of multiple physical models and related them with the phenomenon. For example, she described engaging students with models while she was a substitute teacher, where she built physical models of vespers that represented atoms and molecules that were joined with sticks that illustrated bonds. Additionally, she described incorporating the existing knowledge of scientific models of Watson and Crick to help understand DNA parts and replication. Also, she described that she would use DNA when covering mitosis and meiosis.

> Simba: When I was substitute teaching, we did Vesper models with the ball and the connectors for the bonds, representing atoms and bonds with the sticks making molecules. In biology, looking at cell structure, we compared plant cell structure to the animal cell. We also use the DNA model from Watson and Crick to understand the different parts of DNA replication and later, do like mitosis and meiosis.

Nyati also described his experiences with the use of conceptual models. For example, he explained that he liked to introduce online labs, online simulation, and fryer models when studying evolution to cover the bottleneck effect and the founders' effect.

Nyati: At least in the classroom and being virtual, I like to introduce online labs and online simulations; for example, we are covering evolution right now. So, some simulations cover the bottleneck effect and founders' effects. So, we do group discussions and like the fryer model, for example. Moreover, going over slides to just covering information.

Chui also only exhibited the knowledge of conceptual models such as the online simulations, integrated pictures, and gifts. For example, he explained that he used animated pictures to explain standing waves or free waves. Also, Chui stated that he used Freebody diagrams and equations to show relationships between things.

Chui: I use animated pictures and gifts and, like, stuff like that, that way I could show action within a process. I probably create my models, you know, equations or models. So, in physics, we use models like Freebody diagrams and equations to model a relationship between different things. I always use animated pictures to talk about standing waves or free waves.

Knowledge of Using Scientific Models. The three participants exhibited the knowledge of using scientific models, although they all described the use of conceptual models. However, Simba and Nyati's ideas of using scientific models were more developed than Chui since they engaged their students with models, but Chui only described that he used models for demonstration. For example, Simba described that DNA models were used to describe the helicase enzyme and its activity and appearance; students could observe its movement. Also, she emphasized that online vespers models engaged students by adding electrons to the digital model as they observed its orientation and change.

> Simba: I use DNA to describe helicase enzyme and what it does and looks like, and students can see the interaction. Also, online Vesper models allow students to add more electron groups, and the digital model will respond and change its orientation, making students engaging.

Nyati also denoted that he incorporated simulation models to help students understand the information better and help students understand how such concepts presented in lecture format happen in life.

> Nyati: I use scientific models to help the students and allow them to kind of grasp the information a lot better. So, if you use a scientific model, as a simulation, for example, it brings to life some of these concepts that if it was just in lecture format.

While Chui demonstrated how one could use scientific models, he explained that models are the foundation in classrooms and could describe the concept during learning, such as dissecting animals while teaching biology. Also, he described that, models could be used for demonstration and valuable during data analysis.

> Chui: In physics or chemistry or biology, you dissect animals you mostly do, like demonstrations. We are modeling something in the environment, in a controlled setting, so we can analyze the data and apply that to the concepts that we are learning.

Knowledge of Scientific Model Features. All participants did not demonstrate an understanding of the scientific model features, and they all assumed that model features were model functions. For example, Simba described plant cells and how the process of photosynthesis is involved by identifying the parts of the plant cells and their interaction.

> Simba: Some of the features we looked at plant cells about photosynthesis and some of the features include the parts what they do and interact as well.

Nyati also did not articulate any of the features of models but stated that the model could show the relationship to make things look real in life. Also, such features could be used to understand terminologies.

> Nyati: I think some of the features are it allows some information, especially in biology, and I'm currently teaching biology, and science, but the models kind of almost bring to life what you need to know. Moreover, in this case, at least in biology, and environmental science, there is much terminology to know, and that terminology allows them to grasp information.

Additionally, Chui's understanding was full of misconceptions between models and features of models since he assumed that the features were just the same as models. For instance, he described that model features are used to show relationships between things and could be used to describe something. For example, he described that, models such as microgravity would describe its effect while in the international space station using Newton's law of motion. He also explained that models could be graphs to show the interaction between variables.

Chui: It would be something that's showing something and physics; I would say a model is going to be, you know, something we use to show a concept that otherwise cannot be shown within the classroom. So, in physics, things similar to microgravity or no gravity, how, like the International Space Station, how that affects when you're in space? How does that affect like Newton's laws of motion? Newton's laws of motion, those are models, right? Those are telling you how things interact. Models tend to sometimes exaggerate the interaction, especially within the scientific classroom, just because that is the easiest way to show kids and that makes it click. But models could also be just graph and data points, showing a relationship between your independent and dependent variable. So those are the main features I would think is like showing a relationship or interaction between two things.

Uses of Scientific Model Features. Simba and Chui developed rough ideas on the uses of scientific model features uses. First, however, they described the features of scientific models as the functions of models. For example, Simba described that scientific models' features are used to relate ideas and expand relationships. She further explained that models isolate little pieces and describe the big concept.

Simba: Model features are used for relating the ideas or to expand on the relationships because there are a lot of different working parts in life science. So, the models help to isolate little pieces and describe in the bigger picture by illustrating that in a more active way.

Chui did not exhibit any ideas about the uses of scientific model features**.** However, he believed that models could function to exaggerate students' understanding and relationships between two things. He also explained that model features could be used to explain concepts in ways that could be understood, such as showing the public the effects of diseases such as the virus.

> Chui: Yeah, um, I think we use it to exaggerate a relationship between two things in order to have our students comprehend something. We use models to show the public, what things are interacting, how the virus affects the deaths or illnesses. So, the biggest thing is that scientific models take a concept and forms it into a way that is easily understood and comprehended.

However, Nyati did not portray any model features ideas but instead described that the features could help students understand what they need to learn and pass the test.

> Nyati: I think scientific model features help students understand what they need to know. And they also understand how that information works. And over time, especially with state testing, that is in hopes that using both those methods, allow them to score high on a state test and potentially give them a good future.

Knowledge of the Steps of Scientific Modeling. Only Nyati exhibited the knowledge of “using "steps of scientific modeling, but Simba and Chui did not describe any. For example, Nyati described that the steps of scientific models such as simulation, puzzles, and YouTube videos are used to engage students in class by asking questions and helping them understand the information they need to know.

> Nyati: The experiences that I have had with scientific modeling so far is giving the students information they need to know and why it's important that they need to know by applying things such as labs, simulations, third using puzzle, which pairs YouTube videos with asking questions. So, this, I think all of these steps

kind of come together at some point, allowing a student to understand the information that they need to know.

However, Simba described that she was not sure about the steps of scientific modeling. So, she developed a rough idea of the steps of scientific modeling in which she described that the steps are broader concepts of using models in the classroom.

Simba: I don't know I know what the explicit steps of scientific modeling are, and it could like broader concept of using models in the classroom.

Chui also stated that he was not sure about the steps of scientific modeling. However, he described that step could be used to define a model and teaching, and assessment. He also stated that the steps of scientific models could show relationships of variables among force, mass, and acceleration.

Chui: I'm not sure how many steps are and what they are. But I would say you have to define the model. You use the model, to teach. You can use the model as an assessment tool. Okay, how is force and acceleration related? Well, they're directly related, because if acceleration increases, so does force you know, or, you know, but if you have something like, okay, house acceleration and mass related, well, they're inversely, if one goes up, the other has to go down, in order to keep force the same.

Uses of Steps of Scientific Modeling. All three participants did not understand the uses of the steps of scientific models. However, Chui and Nyati portrayed a little bit of knowledge about the steps of scientific modeling compared to Simba. For example, Nyati explained that steps of scientific models could be applied to enable students to know what is intended for them to learn and its purpose.

> Nyati: I think there are a couple different steps and using the steps allows a student to learn what they need to know, giving also like a, why do you need to know this? and understanding how it works? So, I think a couple of those different steps can be applied to make an efficient scientific model.

Chui also exhibited a rough idea about the understanding of the uses of steps of scientific modeling, but at the same time, he was confused about it. For example, he stated that models are used for teaching and as an assessment tool to understand if students grasped the concept or not by asking questions and students providing explanations. He also explained that the steps of the scientific model would simplify the concept for easy understanding the concept.

> Chui: I'm not sure how many steps are, what they all are. But I would say you have to define the model and you can use it to teach and as an assessment tool to gauge whether your students comprehend the concepts. For example, how is force and acceleration related? You are simplifying a concept for understanding.

However, Simba did not demonstrate any ideas of the uses of the steps of scientific modeling.

> Simba: So, I don't then know what can be done with the steps of scientific modeling.

Knowledge of Engaging Students in Scientific Modeling. All three participants shared different ideas of engaging students in scientific modeling of equal length. Simba expressed her ideas to engage students in discussion in the classroom. For instance, she stated that she used models to engage her students to develop the concept. She also described that she introduced DNA and the enzyme in the DNA model and then asked students to describe the model. Additionally, she denoted that while teaching, she introduced the model and allowed students to develop critical thinking.

> Simba: You can use models in your classroom for discussion, to teach, and to demonstrate abstract or broad concepts. So, we break down the pieces, asking students what they know about things ahead of time like what do you think of DNA? What does that mean to you? And then as we go through different enzymes like helicase the unzipper, and polymerase, then later, I ask them what does it mean? What does that mean for the bigger picture? So, I try to give them the little pieces to get them doing more critical thinking.

In contrast, Nyati explained that he liked to engage students in a hands-on activity such as the lab by introducing the activities students are supposed to cover, such as making an observation, hypothesis, and developing critical thinking while learning.

> Nyati: I like to approach class, especially a science class is a lot of hands-on learning. So, if you're able to kind of create like a hands-on lab by introducing, for example, like observations to hypothesis, and they're able to critically think about what they're learning about, I think that would be a perfect example of scientific modeling class.

Also, Chui explained that he would use models for demonstration and show relationships between things. For example, he would use models while engaging students, such as using the tuning forks to explain sound in different mediums using the same frequencies. He also explained that he dissected an eyeball to enable students to explore it and get an understanding. He described that he would ask his students critical questions to describe what they understood in a modeling class.

Chui: To model, there's a lot of demonstrations you can do. So, we're talking about sound right now. So, we can talk about tuning forks. And, you know, if we hit this frequency with this frequency, what's changing? We can use different models as in Okay, here's the same frequency but through a different medium. Why does that change? But a lab is modeling a relationship, whether it's organic chemistry versus physics or, you know, anatomy. I dissected an eyeball and anatomy class. Well, that's a model, whether it's plastic or real. It's still showing me it's modeling the body parts as modeling the anatomy. So, I think, as a science teacher, your biggest thing is to just let kids explore using models within a lab setting.

Instructional Strategies for Teaching Scientific Modeling. All three participants demonstrated their Knowledge of MBI. However, they only portrayed a little bit of knowledge of the three stages of MBI- teacher eliciting students' ideas, teacher supporting students' ongoing changes in thinking, and teacher and students pressing for evidence-based explanations. For example, Simba described that it was paramount to introduce a concept and build a bigger picture. She also described that she would allow students to manipulate models such as that DNA to get acquainted with it. Finally, she demonstrated the knowledge of teachers and students pressing for evidence-based explanations by asking them questions about the models. However, she did not develop the knowledge of teacher planning for students' engagement.

Simba: Activating background knowledge and then defining what we're working with, and then building the bigger picture. I want them to be able to manipulate the models such DNA, or with cell replication or genetics. Then ask them questions and let them work with the developed models to answer that question.

In contrast, Nyati explained that he would engage students with a model to enlighten students to comprehend concepts.

Nyati: So, I think include in a scientific model is extremely important. Because if they if a student is able to understand why it's important, and it makes learning for them a lot easier.

In comparison, Chui used equation models for explanations. Additionally, he described that he would engage students with different models, such as performing demonstrations using two tuning forks while teaching about sound and using a 3d model to explain the cell. Chui would then ask his students questions about different sounds. He would also use balloons filled with hilum and others with air and have students explain the difference.

Chui: Okay, let me do a short demo of two tuning forks. Let's say I'm teaching sound right now. Why does this one sound different than this one? Then I could give them all tuning forks, and balloons filled with helium versus air and having them explore. If I was talking about a cell, and I have a 3d model of an animal cell, I'm going to use it as a demonstration and show them the relationship to understand such as the equation.

Knowledge of Assessing Students' Understanding of Scientific Modeling. All the participants portrayed the knowledge of assessing students in equal strength. They demonstrated the three stages of MBI: the teacher's eliciting students' ideas, the teacher supporting students' ongoing changes in thinking, and the teacher and students pressing for evidence-based explanations. For example, Simba described that she introduced photosynthesis and cellular respiration and engaged her students with introductory level questions to describe the two processes. Also, Simba expounded that if her students answered the questions. Then, she would prompt them with more complex questions to enable her to identify a misconception.

> Simba: We did photosynthesis and cellular respiration, and my assessment was like the fundamental questions for example, what did these different parts do? Where does photosynthesis take place? What organelle do? So, I know that they know what the pieces mean. So that when I go into more like expansive questions, such as what would happen if we needed oxygen to have cellular respiration happens? What happens when I don't have oxygen? and having them think through? I can look back and see maybe where they have a misconception.

Nyati also described that by engaging students in the lab, they would develop critical thinking and develop explanations.

> Nyati: I think applying a lot of things like labs and using critical thinking and explanations of how you got an answer or why you got an answer would also be beneficial to students.

Chui also explained that he first engaged students with a model such as that of balance by asking students to hang from the ceiling and torque, levers, and force as they are related to gravity for students to understand the concept and their relationships. Also, he asked students to describe the relationship between torque and force. He then provided them with a mobile model and asked them to describe what they understood.

> Chui: You could use something like balance, and students hang it from the ceiling using their knowledge. I also taught them on torque and levers and force due to gravity. Then they used a model that was in the form of a mobile to show that they understood. How those things were all related. How is torque related to force and all those different things?

What Influences Students' Thinking About Scientific Modeling. Simba and Chui described better ways to influence students thinking about scientific models. They expressed the knowledge of the three stages of MBI: teacher eliciting students' ideas, teacher supporting students' ongoing changes in thinking, and teacher and students pressing for evidence-based explanations. For example, Simba shared that when students are introduced and provided with models, it makes learning a lot easier; for example, allowing students to watch the animation for DNA replication and the enzymes involved could influence their thinking, such as describing ideas and being practical.

> Simba: Working with models it's a lot less intimidating. For, example, today, things in DNA replication, were feeling abstract but then we watched the animation, and saw the helicase moving, the polymerase coming in. So, giving them more opportunity to work with models might influence their perceptions to describing ideas and useful.

In comparison, Chui stated that he would use equation models to explain their importance to students, then he would pose a question about scientific modeling and have a session for discourse. He also explained that he would provide students with a chat and data and ask students to describe if the models were accurate because he believed that people could model something that was not accurate and created another session for discourse.

> Chui: I never thought of an equation as a model but once I was exposed to the idea of it showing a relationship. So, I think to influence them to think about that by posing the question, have it a session of discourse. Here's the chart, here's the data now, is this model, correct? So, I think, just holding discourse, to talk about what is a model and what's not. Did they use it accurately because you can model something, and it won't be accurate?

In contrast, Nyati explained that he would use different scientific modeling strategies to provide explanations to students.

> Nyati: So, in that case, what we can do better going forward, is introducing different scientific models, instead of just example, like a more extensive base or reading-based curriculum, as well as emphasizing the why and the way they need to understand this, and how, how can this be applied? Moreover, if you are able to make those connections, it helps the students understand the information a lot better.

Model Specificity. All three participants did not understand that models are specific. For example, Simba described that it was necessary to use similar models when describing plant and animal cells, but she would not permit them to be doo distinct. She, therefore, believed that similar models could allow students to make connections.

> Simba: So, if I'm teaching one lesson, I would want to use models similar to each other. I would want to use a very similar model for my plant cell and my animal cell, but I don't want them to be too distinct. And by having models that are similarly described, they can make those connections more easily.

While Chui also did not understand model specific. He described that he would try engaging with different things, such as animated pictures and gifts.

> Chui: I think as a cheap biggest thing that you do never stop, and knowledge went into effect model might not work the way that you planned it. Work insert you might have to do will last and use a different model I don't think you should be afraid. Things friendly. Do you want to keep it sit through your boxes and sure that they learn? But you know something fails during period one there's no reason why you couldn't change it the next day or the next year or the next.

Nyati also described that he would use many models while teaching one lesson.

> Nyati: I think it's, it's probably best to stick to at least one or two in a class, especially in science, like some of the information that you need to know as it is cut and dry. So there needs to be a lot of explanation as to, for example, cell respiration, like how does that work? And I do not think you can cover that in just one class. So, for example, in some cases, a scientific model may be applied over several classes to I think it just depends.

Summaries of Participants' Knowledge of Scientific Modeling after the Introduction of the Scientific Modeling Activity

Experiences in Teaching and Using Scientific Models. After introducing scientific modeling, all three participants demonstrated a better understanding of it since they all engaged their students in building models and completing projects. For example, Simba described that she used models when introducing a new unit. She also described that she engaged students with physical models such as the Punnett square and the pipe cleaner and beads to help students comprehend the ideas. She also described that she read information about a model but came up with her version.

> Simba: We use models when we're starting a new topic in a unit. So, things like photosynthesis, Punnett squares, or crossing over will use models as a visual anchor for getting more familiar with that concept. I found a model online for crossing over that used Barbies, but I didn't like the way they showed it. So, I came up with pipe cleaners and beads.

In contrast, Nyati described that he introduced the process of micro-remediation and worked with students to build a micro-remediation used to fix contaminated air in the environment. As a result, students were able to complete their projects about micro-remediation and completed a mushroom project.

> Nyati: We were going over-micro remediation, and I worked with the students, to model, basically, how a scientist goes about using micro remediation to fix contaminations in the environment. So, I worked alongside them. And then also provided examples of like real-world examples of using micro remediation. So,

they did a project about it, but we also started growing our own mushrooms as well.

Finally, Chui possessed the knowledge of creating and using physical models. For example, he highlighted that he created lenses and incorporated them in class. He also stated that he taught his class using real-life lenses of Fenway and prisms to see the rainbow, which allowed students to understand the concept. Additionally, engaged students to create lenses with laser beams with different lenses shapes, and they placed them on a whiteboard to allow students to see the refracted light from different angles. Chui further explained that students could observe how the index of refraction affected light and affected light bending in a medium.

Chui: We had like smell's, law, and you know, making sure that I'm using like real-life lenses to Fenway and like prisms to see rainbows and things like that helps my students understand the concept I'm trying to teach. I wouldn't say that I always create my own, but it was just something that I did, using supplies that I had available to me. But I think that there are great resources out there with very smart people. So, I created the lenses, one where we had a laser beam, and we had different shapes of lenses, and then you could put it on the whiteboard, and the light refraction at different angles. And that allows you to see how the index of refraction affected light bending through a medium.

Knowledge of Using Scientific Models. Both Simba and Chui developed a better understanding of using scientific models than Nyati since Simba and Chui described engaging students with models and answering questions. However, Nyati only described the process of protein formation from DNA. For example, Simba described that, models are more accessible to visual and tactile learners. She also explained that engaging students with physical models would allow students to develop the experience of manipulating them to understand DNA as it relates to crossover and the relationship between DNA and chromosomes and genes. Further, she denoted that, scientific models are helpful in research to study the consequences or answer questions. Nevertheless, she explained she would use the model to engage students during meiosis and mitosis and asked them to explain them, and that would help students develop critical thinking and the understanding of crossover and its relationship with genetic variation.

> Simba: Models are accessible to visual and tactile learners. So, when we have a model, it gives them a physical thing to look at and to manipulate and to understand crossover, DNA, and chromosome is, as it relates to DNA and genes. But in discussing crossing over and why it's important, they kind of just took away, it is important, but can you explain why? So, when we used a model to demonstrate, let's do miosis, without crossing over, then let's do meiosis with crossing over, we can see the difference in our results. And now they have the piece of Oh, therefore that's important as it relates to genetic variation in a population. think that rather, like instead of just teaching students how to understand concepts. Models are useful for application and respond to a question such as the consequences.

In contrast, Chui understood that models are essential for relating to the phenomenon. For example, he described that, physical models are essential for relating the concept to students' daily lives. He also explained that models allowed students to see how polarized sunglasses and unpolarized lenses enabled them to view different light orientations and different planes, which gave them an understanding of why people wear contact and networks or glasses and networks. Additionally, he described that models could create discourse, and students could talk about any questions they might have, which would help them comprehend and retain information.

> Chui: They help relate the concept that you're teaching to the students 'everyday lives. So, like I said, seeing how like polarizing sunglasses or polarizing lens blocks light, and then how you could put on the polarized sunglasses and see the difference between you know, different light oriented and different planes. But that shows them that there's a reason why we can wear contacts and networks or glasses and networks. So, it's a great way to introduce a concept and then create a discourse within the classroom talking about the concepts or what questions they might have, or what they already know and that helps students remember why they learned a certain concept.

While Nyati did not gain any ideas on the uses of scientific modeling after introducing scientific models since his responses were related to those mentioned at the beginning of the scientific modeling activity, for example, he described that he would integrate real-world explanations and the process of DNA transcription to RNA and RNA translation to protein and the effect of Covid-19.

> Nyati: I've been focusing on real world applications, example of, especially in biology is like. DNA will be turned into RNA, which will then be translated or transcribed into RNA, and then RNA will be translated into proteins. So, using the model of something like a real-world application, such as the COVID-19 vaccine, and relating it to what we're learning in the classroom, I think is really powerful.

Knowledge of Scientific Model Features. Only Simba portrayed the knowledge of understanding the features of models. For example, she stated that she engaged her students by providing them with a template that contained some black and white beans, and she asked them to describe it. Simba also explained that her students could manipulate and understand the concept.

> Simba: I gave them a little template and some black beans and some white beans. And they were able to describe what that was representing. So, the template is the Punnett Square. The beans are the illegals and then they were able to manipulate those things and then gain their own understanding and facility with that concept.

Nyati did not understand the meaning of the models' features. He explained that model features are those of transcribing DNA to RNA and RNA translated to proteins. Additionally, he stated that features of models are used to describe the project.

Nyati: I think some of the features can be something like I gave the example of DNA being transcribed to RNA being translated protein, but that can also be a different scientific model could also be going out of your way to also explain how a project is going to be done and showing.

Chui also did not understand the features of models. For example, he stated that features are used to demonstrate and show the relationships between concepts, between humans and the earth's gravity, and show how the cell looks like for students to develop the experience.

> Chui: Scientific model could either be demonstrating or showing a concept or relationship between, two different things. How can we model the interaction between myself a human and gravity of earth, right, the pole that gravity has on

me? I think more of hands-on models, such as showing what a cell looks like in a much bigger scale and being able to show students physically what something might be that they might not otherwise be able to physically.

Uses of Scientific Model Features. Chui described better knowledge of model features' uses than Simba and Nyati. For example, Chui explained that models' features are used to explain things that are challenging to explain, and that could not be easily seen while doing modeling.

Chui: Models features help with recalling of information, information retention. I think other features, it just helps explain that otherwise, wouldn't it be as easily shown, like a show something that's hard to explain sometimes. So, I think that helps. models can help explain things that are hard to explain with words.

Simba did not portray any knowledge gain since she mentioned that students could manipulate the features and use them during learning.

Simba: So, the features Yes, like they're manipulated, like the one that I would comment on is it's able to be manipulated and students are able to use it.

While Nyati did not gain any ideas on the uses of the features of scientific models, instead, he described the uses of features as those used to understand the concept. For example, he stated that the model provides the physical layout and structure.

Nyati: They can be used for basically helping out a student understand the concept, a lot of what at least what I figured out is a lot of students, if you just explain something verbally, and they don't understand how to say something in biology happens, and they don't get that visual idea of how it works. So, I think one of the biggest things with scientific models is that it provides a, it can provide like a physical layout and structure to how certain content or certain topics are viewed and can help kind of break down some of the complexities of that.

Knowledge of the Steps of Scientific Models. All the participants exhibited knowledge of at least one step of scientific modeling each after introducing scientific modeling. For example, Simba understood the evaluation step of scientific modeling, and she described that she would describe the relationship between the phenomenon and the model and use the model to solve a problem, and students would apply the model while learning monohybrid crosses with beans. She also described that the students understood models because they answered questions; they would retain the information and apply it in future topics such as blood types and sex-linked traits to solve problems and predict.

> Simba: We look at an overview of the phenomena and then I introduced the model, and we describe how those pieces of the phenomena are related to the model. I will then give them a tool and have them perform the process and if this step didn't happen in this part of the model, then what would happen from that? So, the steps then would be like the student's application of the model, and they will use that as a tool for future learning to understand monohybrid crosses with the beans. When going into things like blood type and sex-linked traits, and they still have that understanding of the model to start problem solving and as predictive support.

While Chui exhibited a rough understanding of the steps of scientific modeling, he described that the steps of scientific modeling help would help him create models and explain them to students.

Chui: I think using these, these steps of scientific modeling, it will help me create more of my own models that are familiar to me and therefore, I can explain better to students and use it more effectively.

Also, Nyati described one step of scientific modeling, using. He highlighted that he would engage students using a secondary succession of a world-fire example. He explained that if he provided manipulatives to students to use, they would be able to gain knowledge.

Nyati: I've had a couple different experiences, especially with the modeling, looking at a specific type of concept, such as I gave the example of secondary succession. So, I gave an example of a wife wildfire coming through, if I provide manipulatives that students are using to figure out and build on top of the model that I gave, then the students are applying the information about that specific model.

Uses of Steps of Scientific Modeling. All the participants expressed their ideas about using the steps of scientific models. For example, Simba demonstrated knowledge gain in understanding the uses of the steps of scientific modeling. She stated that the steps would help to introduce a topic. Also, Simba described that she would give students pieces and ask them to explain what they represented, and students could use the steps of scientific modeling to predict those pieces, such as the pipe cleaner and beads, and students' explanations would help Simba identify a misconception from students.

Simba: They can support the introduction of a topic. So, I'll give the students the pieces and ask them to predict what they think the pieces are going to represent. I gave them the pipe cleaners and the beads, and then they were able to use that and instead of me explaining what the model is, they offered up predictions for Oh, well, the pipe cleaners, they might be DNA. And so that also helps me to identify misconceptions about what DNA and chromosomes are, how they're related.

Chui also described that scientific modeling steps are essential when creating models for classrooms to explain concepts that are hard to understand.

> Chui: Using those steps of scientific modeling, we can then create these models to assist us in the classroom and help explain the concepts that otherwise wouldn't be easily explained.

While Nyati denoted that he would allow students to build their ideas about using the characteristics of the given models, he also stated that he would work alongside students to make them confident about their work.

> Nyati: especially with scientific modeling, the whole idea that I see as it's just like, allowing students to kind of build on top of their knowledge through the different characteristics provided with a model like the one for secondary succession. But also, to work alongside the students and provide material in a way that they don't have to question what they need to do.

Knowledge of Engaging Students During Scientific Modeling. All the participants described ideas of engaging students in a scientific modeling class. For example, Simba developed a better understanding of engaging students with the pipe cleaner and beads models since she stated that she would use a model to support struggling students to support their understanding, but with more advanced students, she would ask students to answer more complex questions that would require application and creativity.

Simba: If I have students that are really struggling with a concept, they can use the model such as the pipe cleaner and beads to support their comprehension. So, I can give them like simple problems, they can use the model to start integrating that problem solving on their own. But when I have advanced students and ready to move on, I can give them a more complex problem and they can use the model in the same way but more application and creativity.

In contrast, Chui described the related information he shared at the beginning of the scientific modeling activity. For example, he stated that models would help students understand their function by showing the model's relationship and the concept.

Chui: I think if students can think of them in that, terms, and might help them, break it down and be able to, in the future, break down things on their own. And think of how you could model the relationship or model a concept that maybe the teacher does not provide a model for.

Nyati did not portray any knowledge gain since he gave related experiences like those, he mentioned at the beginning of the scientific modeling activity. For example, he explained that if students were engaged with manipulative variables, it would allow them to develop critical thinking.

Nyati: when you're manipulating different variables within an example or things like that, like it gives the students an opportunity to think a little bit harder about what they're learning about, but also kind of add a little fun to it.

Instructional Strategies for Teaching Scientific Modeling. Both Chui and Simba developed strategies for engaging students, while Nyati did not exhibit any ideas for teaching scientific modeling. Simba and Chui expressed their ideas in support of the three stages of MBI: teacher eliciting students' ideas, teacher supporting students' ongoing changes, and teacher and students pressing for evidence-based explanations. For example, Simba described how she engaged her students with more complex models such as Punnett square, explaining the parents and the possible offspring. She also described how she engaged her students to dissect a flower and led them with open-ended questions, and students made Inquiries about how Gregor Mendel avoided self-fertilization and if flowers reproduced asexual and sexual reproductions. Additionally, she explained that students manipulated the flower by breaking it and examining the different parts, and they could argue with evidence when responding to the teachers' questions.

> Simba: So, we did a flower dissection; I asked them how Gregor Mendel prevented his flowers from like self-fertilization? and do flowers reproduce sexually or asexually. And so, they had the flower itself to break it apart and look for different pieces. So, they can use that model to help respond to Inquiry, and then develop their own questions as we go. But also, like Punnett squares looking at available data and then engaging in an argument from evidence. For example, when they have parent A and parent B, how many offspring would be x or whatever They could look at what they have on the Punnett Square and then using that process, understanding what's involved then defend to me by engaging argument from evidence.

While Chui portrayed his conceptual ideas of strategies to use in the classroom by incorporating the stages of MBI, he described that he could introduce a model without telling students much about it, and then he would ask students to describe its application in real life. He would then describe that after students' explanation, he would explain to students, what models are and allow them to create their own.

> Chui: subconsciously, you could introduce, and you can teach them more about it and be like, hey, we've already been using this for a long time. Can you think of ways we could use this in the future? So, then they can start applying it to the real world. I think then explaining to them what a model is and how they can create their own.

Nyati did not exhibit any knowledge gained on the strategies of using MBI. Instead, he described that teaching using a model would allow students to accomplish their work at the right time, and that could make them not struggle.

> Nyati: Some that may not be able to grasp some of the grasp and some of the concepts as easy the idea of different differentiation, especially when you're using a concept like modeling, it allows the students you can provide extra information for them so that they can get to the end result in an adequate amount of time, or the same amount of time as somebody that may not struggle as much with the material provided.

Knowledge of Assessing Students' Understanding of Scientific Modeling. All three participants described ideas to assess students. For example, Simba explained that she would allow students to manipulate a model and ask them critical questions to enable her to identify a misconception. She also assessed students by using physical models of Punnett square to engage students, and she described that model could allow her to understand students' thinking. So, she allowed students to manipulate the model, and they were able to describe the model, and then she was able to identify a misconception because the student was using the wrong terms to explain the process of crossover.

> Simba: The model can help to explain their thinking, but to help me to see where their misconceptions are. So, I had a student who was basically using the word genotype in place of a legal or using them interchangeably and didn't seem to understand that an illegal is one. And so, in her showing me on her Punnett Square, I caught that because as she's moving the beans around, I'm hearing these words kind of used as though they're the same word. But also getting them to, answer a question that I posed using the model, for example, crossing over when I asked, why is this process important when they can go back through and like, twist the pipe cleaners together, and then show me Well, if I don't cross over, I have two versions of an offspring. And if I do crossover, now I have four that I can give to an offspring, and they can use that model to support their thinking and descriptions.

In comparison, Nyati stated that he engaged students in project-based, which allowed him to evaluate students' understanding. For example, he described that project-based allowed students to apply the previous knowledge learned in class and evaluate how much they understood or not. However, there was a misconception when he described using multiple choices to assess students.

> Nyati: I think, especially with project-based learning, and applying projects, to the concepts being covered in class, I think that allows the student to apply that information that they've learned, and you can see how much they've actually understood it. And I mean, of course, there's always going to be multiple choice

> questions out there. And I think that's probably a pretty safe way to also assess student understanding.

Chui also explained that he would ask students to describe a model equation of force, mass, and acceleration. He also explained that he would ask students to describe a model showing two things traveling next to each other but at a different speed.

> Chui: I like challenging them to think giving them like a relationship, F equals MA. Now, how would you model that for me? How would you show me that to make me understand F equals MA? So, I would challenge my students to think of their own way to model a certain concept, whether that's circular acceleration, why when two things traveling in a circle next to each other, are going different speeds.

Students Influence Thinking Scientific Modeling. Only Simba described the ideas that would influence students learning of scientific modeling. For example, she described that she engaged students with physical models such as the pipe cleaner and beans and flowers and asked students to describe them, and she would identify a misconception. Additionally, she highlighted that when students utilize the models for photosynthesis and cellular respiration, they could better understand the organelles in the cell fit in the organism. She also denoted that using a visual model could be significant for tactile learners; to understand the model's components.

> Simba: I've been describing a lot of like physical models, like pipe cleaners and beans, and flowers and whatever. But there are models that are just like visual representations that are still useful for tactile learning, because you can like, look through a system. So, like when students are like, approaching a model for like,

photosynthesis or cellular respiration, they have to understand because if they don't understand that, then there are other misconceptions that just naturally get woven in. But there are models that are just like visual representations that are still useful for tactile learning.

In contrast, Nyati described that he would introduce different modeling learning strategies to benefit different types of learners.

Nyati: So, some people may be advanced learners, some people may have an IEP, and struggle with some of the information a lot. So, if you're using modeling, you can implement all of those different things that allow for each type of learner to understand and kind of appreciate what they're learning about, especially in biology.

However, Chui decreased his understanding of the knowledge of influencing students in scientific modeling. For example, he explained that he would break the model not to intimidate students and ask them why such a model was significant.

Chui: I think if you use them yourself, I think being a good leader, as a teacher and showing pipe sample is really what's going to set you apart. I think the other thing is that, you know, you need to break it down in a way that doesn't seem intimidating. And it doesn't seem like this big complex thing. And another thing is, I think you have to, you know, you have to show relevance, why is it important to them? I think that influences them thinking about it, because if they if students don't think it's important to them, they don't care and they're not going to learn it, they're not going to do it. They're not going to, you know, all the different things, but I think, like I said, you know, showing kids why it's important how they can use it in their everyday life, to think about things happening around them, we'll help them understand why it's a really good concept to learn.

Model Specificity. Only Simba understood that models are specific. For example, she stated that she would only use similar models while teaching. For example, she described that when using Punnett square, she filled the box with letters but at the same time and permitted students to type letters or could use beans to represent the same model. She also described that she would use one version of the model for students to understand how chloroplast fits onto a cell when introducing a topic.

Simba: I would not use two models that are not similar to each other. For example, like with Punnett squares, I let them use letters and like I let them type in the illegals and fill in the box with letters, if that is something that works for them, but they also let them use things like the beans as a support. But those models are similar, because the beans are just a different way of representing the letters. So especially introducing a concept I would use like one version of a model for photosynthesis. And just to get us all to understand like, what's the chloroplast? How does it fit within the larger cell, what makes a plant cell different than an animal cell and like that then can be used if we understand this model?

While Nyati developed a misconception by explaining the model specificity, he explained that he would teach using different models to accommodate different types of learners depending on their needs.

Nyati: So, using a model that may be more for visual learners, and just using that for one class and not giving the opportunity for other students to apply the information I provided. I think that that could be a potentially problematic when you're looking at if students are trying to conceptualize the information, but also for them to just not want to learn about it because it's not how they want to learn.

Chui also did not understand that models are specific since he discussed that using different models would benefit.

Chui: yeah, I think as a cheap biggest thing that you do never stop, and knowledge went into effect model might not work the way you planned it. Work insert you might have to do will last and use a different model I don't think you should be afraid. Things friendly. Do you want to keep it sit through your boxes and sure that they learn? But you know something fails during period one there's no reason why you couldn't change it the next day or the next year or the next.

Description of Participants' Codes about Scientific Modeling before the Introduction Scientific Modeling Activity

This section identified the codes across all three transcribed interviews before and after the participants were introduced to the scientific modeling activity. Four matching codes were captured closely related to the following: construct, evaluate (using & features of models), Revising, and Inquiry, as described below.

Evaluate. All three participants demonstrated their knowledge of using scientific models. However, Simba demonstrated a more excellent understanding of scientific modeling than Nyati and Chui. For example, Simba discussed the importance of using the existing knowledge of scientific models such as DNA, vespers models, and hands-on activity and applied them while in a scientific modeling class. While Chui only mentioned that models are used for explanations and show relationships, Nyati stated that scientific models are used for comprehension.

Simba and Chui demonstrated the knowledge of features of scientific models, while Nyati did not. For example, Simba described that scientific model features could define different model parts, show the interaction between other model parts, relate ideas, establish relationships between features, and manipulate to understand a model. Chui described that model could describe the relationship between acceleration and mass as they are related to force. However, Simba described in-depth features of scientific models compared to Chui.

Description of Participants' Codes in Scientific Modeling after the Introduction Scientific Modeling Activity

Evaluate. After being introduced to the scientific modeling activity, Simba and Chui revealed the scientific uses of models, while Nyati did not. Simba and Chui expressed the understanding of scientific knowledge at equal length. For example, Simba exerted that the existing knowledge of scientific modeling could be used to build a model. Also, developed models can be used to identify and solve the existing problems, conform one to learn the model. Chui also signified that the existing knowledge of smells could be used to introduce concepts, the existing knowledge of Fenway lens and Prisms could be used to understand the idea through watching the rainbow, and the existing knowledge of scientific modeling could be used to build lenses to allow the refraction of light at different angles.

Only Simba and Chui denoted the knowledge of features of scientific models after the introduction to a scientific modeling activity, while Nyati did not. For example, Simba described that scientific model features could be manipulated to study the phenomenon and make predictions during scientific modeling. While Chui portrayed a rough idea of scientific model features such as showing things that are hard to explain, recalling and retaining the information, and showing relationships in models such as the equation.

Description of Participants' Codes about Model-based Inquiry before the Introduction Scientific Modeling Activity

Scientific Inquiry. Simba and Nyati demonstrated the knowledge of teacher planning for engagement, while Chui did not possess any knowledge. For example, Simba recorded various ways she plans for scientific modeling class before executing such plans. For instance, Simba considers what model to bring to class while teaching scientific modeling and how she will be represented to meet the student's needs, and it is essential to allocate students enough time to engage with scientific models during scientific modeling, which could influence their perception of modeling. While Nyati stated that planning for hands-on activity is essential when approaching a class, the existing modeling knowledge could be used to develop a hypothesis. However, Simba demonstrated a better understanding of teacher planning for engagement than participant two simply because she planned for the type of model to bring to the class to execute it to ensure it is interactive. Also, she discussed allocating enough time for her students to engage with a model. While Nyati only mentioned the importance of planning for hands-on activity and developing hypotheses.

All three participants demonstrated different ideas of teachers eliciting students' ideas at equal length. For example, Simba portrayed different techniques to prompt students, such as the existing DNA knowledge to influence and aid in the students learning, asking students about open-ended questions regarding any prior DNA knowledge, and incorporating the role of different DNA enzymes and online animations and vespers models to help students comprehend the work of various enzymes. Nyati discussed introducing a concept to make information a lot easier. Also, introducing varied models may influence students learning, such as during evolution, the founders' effect, and hands-on activity asking students questions. Chui also demonstrated varied ideas of teachers eliciting students' ideas such as using existing knowledge of scientific modeling, engaging in discourse, asking students' questions, introducing different model types such as mobile model, tuning folks, 3d model, and lab activity to describe the importance of the dissected eyeball to expose body parts.

Also, the three participants demonstrated that the teacher supported students' ongoing changes in thinking and analyzing ideas at equal length compared to Nyati. For example, Simba described using the existing knowledge of DNA and DNA enzymes, engaging students in critical thinking by asking open-ended questions, providing assessments, and identifying misconceptions.

Nyati demonstrated a few ideas on supporting students' ongoing thinking and analyzing views. For instance, he stated that models could make learning a lot easier. Moreover, introducing various models could influence students thinking by integrating the existing knowledge of scientific models such as the Frayer models, which can promote students' understanding and ask students their questions. While Chui demonstrated the knowledge of using the existing knowledge of scientific modeling, introducing different model types, engaging in discourse, and asking students' questions.

For example, the participant described the use of Freebody diagrams, animated related to waves, lab demonstration of a 3d, and frequency from different mediums.

All three participants demonstrated teachers' knowledge of pressing for evidence-based explanations at equal strengths. For example, Simba mentioned evaluating students, asking students general questions, and being complex. In comparison, Nyati described engaging students with the assessment of critical thinking. Chui also described engaging students in discourse to promote questions on accuracy and correctness and mobile models and assessing students' understanding.

Description of Participants' Codes about Teaching Scientific Modeling after the Introduction Scientific Modeling Activity

Scientific Inquiry. All three participants exhibited the knowledge of teacher planning for engagement after the scientific modeling activity at equal length. For example, Simba stated that the existing knowledge of scientific modeling could be used to build Punnett square and pipe cleaner for her class. In contrast, Nyati exemplified that the knowledge of micro remediation can be used to design students' projects such as mushrooms and fix environmental contamination. Chui also described that model could be developed to help plan what to teach to ignite students to comprehend and retain the information on scientific modeling.

All three participants manifested the knowledge of the teacher eliciting students' ideas. However, Simba and Nyati demonstrated more excellent knowledge to elicit students' ideas than Chui. For example, Simba described that the existing modeling, such as the Punnett square, could be used to develop a model and relate to illegal, dominant, and recessive genes. In addition, the crossover can be used to explain how it corresponds with DNA, genes, and chromosomes. Also, pipe cleaner models can ask students to predict what type of phenomenon the model relates with. Nyati denoted the existing knowledge of DNA, RNA, and protein could be used to explain how DNA is transcribed to RNA and RNA translated to proteins; also, the existing knowledge of scientific modeling micro-remediation could be used to fix contamination in the air, describe covid-19 Vaccine, and design students' mushroom projects. While Chui only asked students to describe two things traveling in a circle next to each other but at different speeds by building the model itself.

All three participants described varied ideas of teachers supporting students' ongoing changes in thinking and analyzing ideas. For example, Simba described using the existing knowledge of DNA could be used to describe the relationships among DNA, genes, and chromosomes. She also used the existing knowledge of scientific modeling to design the Punnett square that helped students differentiate among the illegal, dominant, and recessive genes. Nyati denoted that the existing knowledge of DNA, RNA, and Protein could describe DNA transcription to RNA and RNA translated to protein. Also, Nyati exploited the existing knowledge of micro-remediation to engage students to design a project to fix air contamination. Also, Nyati designed and engaged students to complete a mushroom project. While Chui asked students to describe two things traveling in a circle next to each other but at different speeds by building the model itself.

Even though all the three participants exemplified the knowledge teacher supporting students' ongoing changes in thinking and analyzing ideas, Simba and Nyati demonstrated rich knowledge compared to Chui. For example, Simba and Nyati engaged students with building models, manipulating, and asking questions on models such as the

Punnett square, pipe cleaner, micro-remediation to fix air, and completing the mushroom project. While Chui only asked students to describe two things traveling in a circle next to each other but at different speeds by building the model itself.

All three participants demonstrated the knowledge of teachers and students pressing for evidence-based explanations. For example, Simba stated that the crossover process encouraged students to think critically and answer complex questions like Gregor Mendel's self-fertilization and sexual reproduction in flowers. In addition, the Punnett square model enabled the scaffolding process to yield open-ended questions to identify a misconception. Nyati described that project-based learning completed by students enabled him to evaluate students. Chui stated that he used models to ask students to describe the relationships between force, which is equal to mass, and acceleration.

Although all three participants possessed the teacher's knowledge pressing for evidence-based explanations, Simba outweighed Nyati and Chui. For example, she encouraged students to answer complex, open-ended questions, which required critical thinking, which enabled them to identify a misconception.

Themes

The following two themes were established after data analysis.

Knowledge of Building Models

All three participants possessed the knowledge of building models. For example, Simba built and engaged students with models such as Punnett square, explaining the parents and the possible offspring. She also engaged students to dissect a flower and led them with open-ended questions, and students made an inquiry about how Gregor Mendel avoided self-fertilization and if flowers reproduced asexual and sexual reproductions. Additionally, she explained that students manipulated the flower by breaking it and examining the different parts, and they could argue with evidence when responding to the teachers' questions. Additionally, she built a pipe cleaner and beads models to support struggling students to support their understanding, but with more advanced students, she would use the model to give them models to answer more complex questions that would require application and creativity.

Nyati also engaged students in introducing the understanding of the model of micro-remediation, and he engaged students to complete their micro-remediation projects and developed a mushroom project.

Chui built Fenway and prisms to see the rainbow, which allowed students to understand the concept. Additionally, he also engaged students in creating lenses with laser beams with different lenses shapes, and they placed them on a whiteboard to allow students to see the refracted light from different angles. Chui further explained that students could observe how the index of refraction affected light and affected light bending in a medium.

Knowledge of Using Existing Knowledge of Scientific Models

All the participants possessed the knowledge of incorporating the existing models. For example, Simba engaged students with DNA which allowed students to develop the experience of manipulating them to understand DNA as it relates to crossover and the relationship between DNA and chromosomes and genes. Simba also incorporated online vespers models, which engaged students by adding electrons to the digital model as they observed its orientation and change.

Chui also integrated animated pictures and gifts to describe free waves and standing waves. While teaching physics, Chui also utilized free body diagrams and equations to describe relationships between things. He also explained that he integrated animated pictures.

Nyati described that he would utilize the existing knowledge of world-fire to engage students using a secondary succession using world-fire.

Changes in the Knowledge of Teaching Scientific Modeling and the Assignment. This section will explain any possible data change experienced in teaching scientific modeling and the Assignment after the participants were exposed to scientific modeling. The changes were outlined by comparing the knowledge of teaching scientific modeling at the beginning and end of scientific modeling with the Assignment. This section will also answer research question 2.d. How do UT graduate science preservice teachers understand teaching scientific modeling and the assignment change at the end of the scientific modeling activity?

Simba portrayed a better understanding of the knowledge of scientific modeling in the Assignment, in equal length with the knowledge of teaching scientific modeling after the introduction of scientific modeling activity compared to before the scientific modeling activity. In the Assignment, she engaged her students with modeling by first introducing the crossover process, providing them with picture models, and playing with animation to understand the topic. During crossover, Simba described how she would engage her students to make two X's out of pipe cleaners; one X would represent one color, the other X a different color, and the Xs would represent chromosomes. She described that each leg of the chromosome would represent two sister chromatids joined at the twisted "centromere" in the middle, where students will add three beads. Next, students would bring their two chromosomes together and twist two non-sister chromatids together to represent crossing over and exchanging a bead from each "mom" and "dad" in a corresponding space, enabling them to describe their working process. Overall, after introducing the scientific modeling activity and in the Assignment, the participant described detailed knowledge of the understanding of scientific modeling and how to engage students with doing the scientific modeling activity before introducing scientific modeling.

Nyati's Assignment and the understanding of teaching scientific modeling were of equal length and higher than before introducing the scientific modeling activity. In the Assignment, Nyati described how he would model with his students about second Newton's law of motion to show the relationship between mass and acceleration. Nyati also described how he would provide students with balls with varying amounts of sand to describe the relationship between mass and acceleration. When the balls drop into the sand from the same height, the sand on the floor will be displaced; the dropping amount will depend on the ball's mass. Also, Nyati described that he would use physics cars with varying masses and apply force to each car to see the difference in acceleration.

Chui did not describe the modeling process in detail in teaching scientific modeling as he did before and after introducing the scientific modeling activity. He did not engage students with the modeling activity but described using words to fit in an ecosystem. For example, he described the concept of succession by providing students with a background story of wildfires news, and students were provided with individualized note cards with a name, picture, and a description and were asked to figure out the order that plants would grow back after a destructive fire that burnt everything in its path, and they described the phenomenon.

Summary

This chapter provides the data collected from three participants, including the two interviews and one assignment. Also, this chapter provides the summary of the comparison of the three participants' interviews one and two and the comparison of interview two and the assignment. Additionally, this chapter provides coding and the types of themes that emerged from the data.

Chapter 5

Discussion

This chapter interprets the findings of the three participants. The participants improved in their knowledge of scientific modeling and Model-based Inquiry after being introduced to scientific modeling**.** This study explored the science graduate preservice teachers' knowledge of scientific modeling and Model-based Inquiry. The exploratory single qualitative case study was utilized during semi-structured interviews to explore what the graduate science preservice teachers know about scientific modeling and Model-based Inquiry in methods of teaching science course. The interviews were conducted virtually twice, at the beginning of the scientific modeling activity and the end of the scientific modeling activity. Additionally, the participants completed a teaching assignment on scientific modeling.

Studies have revealed the importance of scientific models to develop explanations and make predictions; however, teachers have not prioritized its relevance in science education since they do not know scientific modeling (Valente, Sarreira & Mauricio et al., 2020; Cheng & Lin, 2015; Kenyon et al., 2011; Davis et al., 2010; Bennon, 2021). Also, science preservice teachers are limited in understanding the importance of models to meet the needs of scientific teaching and learning because they do not have experience in modeling and, therefore, lack expertise (Lorao, 2019). Hence preservice teachers are not prepared to teach scientific modeling (Valsconcelos & Kim, 2020). Therefore, this study focused on answering two overarching questions.

1. What do the University of Toledo (UT) graduate preservice science teachers know about scientific modeling in methods of teaching science courses?

a) What do UT graduate preservice science teachers know about scientific modeling at the beginning of the scientific modeling activity?

b) What do UT graduate science preservice teachers know about scientific modeling at the end of the scientific modeling activity?

c) How do UT graduate science preservice teachers understand scientific modeling change at the end of scientific modeling activity?

2. What do UT graduate science preservice teachers know about Model-based Inquiry during the teaching science course?

a) What do UT graduate science preservice teachers know about Model-based Inquiry at the beginning of the modeling activity?

b) What do UT graduate preservice science teachers know about Model-based Inquiry at the end of the activity?

c) How do UT graduate science preservice teachers understand the change about Model-based Inquiry at the end of the scientific modeling activity?

d) How do UT graduate science preservice teachers understand about Model-based Inquiry and the assignment change at the end of the scientific modeling activity?

This chapter will discuss the extent to which the preservice science teachers know scientific modeling before and after the introduction of scientific modeling activity. Also, this chapter will discuss the extent to which the preservice science teachers know about Model-based Inquiry before and after the introduction of scientific modeling activity. The interpretation in this section will follow the following 1. Teachers' knowledge of scientific modeling 2. Teachers' knowledge of Model-based Inquiry 3. Also, this section will discuss the implications of scientific modeling activity in teacher preparation to teach science classes. Finally, the study's limitations, future study recommendations, and the conclusion are also discussed.

Teachers' Knowledge of Scientific Modeling

Scientific modeling is a scientific practice meant to prepare elementary and middle school science teachers by engaging students with authentic scientific inquiry (Teo et al., 2010). There are four steps involved in scientific modeling (Kenyon et al., 2010; Kenyon et al., 2011; Chiu & Lin, 2019), and the four steps scientific modeling are construction, using a model, evaluating, revising. Hug (2008) suggested that instructional activities changed preservice teachers' understanding of scientific modeling. Also, studies by Schwartz and Skjold (2012) revealed that teaching the nature of scientific models in undergraduate science courses to prospective elementary and middle school teachers increased their understanding of scientific models to represent scientific ideas and their explanations.

Teachers' Knowledge of Scientific Modeling before the Introduction of Scientific Modeling

The findings suggest that, in general, the participants portrayed the knowledge of understanding scientific modeling before they were introduced to scientific modeling activity, although not all the scientific modeling steps were described. These findings are inconsistent with that of Garrido & Couso (2016), who asked the preservice teachers' choice of teaching activities that had a higher impact on their learning and found that preservice teachers possessed all the elements of scientific modeling ideas of use, express, evaluate and revise models. Therefore, this study will discuss each of the scientific steps captured in the participants' responses.

Evaluate. This is one of the steps of scientific modeling that the participants were expected to portray during their responses on the knowledge base of scientific modeling. It emerged that all three participants portrayed their knowledge of the step of scientific modeling evaluate before the introduction of scientific modeling.

Using. Using is one of the sub-steps of evaluation, scientific modeling. It emerged that all three participants possessed the knowledge of using scientific modeling before they were introduced to scientific modeling activity. For example, Simba described that she did Vesper models with the ball and the connectors and incorporated the DNA model from Watson and Crick to understand the different parts of DNA replication. Nyati also described using scientific modeling by incorporating online labs such as online simulations to cover the bottleneck and founders' effects. Finally, Chui described incorporating Freebody diagrams and equations to model a relationship between different things.

These findings suggest that all three participants had previous experiences using scientific modeling, which was well detailed and applied in their study area. This study also reveals that the participants were confident about using scientific modeling in their content areas; however, the stated uses were limited since they revolved about using a scientific model while discussing science and asking questions to students. However, this study aligns with Davis et al. (2010), who stated that in the beginning, teachers have ideas they can use to explain the relationship between models and the phenomenon; however, teachers may not understand that scientific models are used to make predictions. The participants did not incorporate the uses of scientific models to describe and make predictions.

Feature of Scientific Models. The features of scientific modeling are one of the sub-steps of evaluate. The features of scientific models help to understand the world based on scientific knowledge and make predictions.

Simba and Chui demonstrated rough ideas for understanding the features of scientific models. For instance, Simba described that, students could manipulate the scientific modeling features. In contrast, Chui described that, models are used to describe something. These findings suggest that it can be well ascertained that the two participants possessed prior knowledge of the features of scientific modeling. However, Simba and Chui did not fully understand the features of scientific modeling since they did answer the appropriate question on scientific modeling features. Therefore, it cannot be established whether Simba and Chui understood the meaning of the features of scientific modeling.

Overall, Nyati did not know the features of scientific modeling. Also, the participants did not demonstrate construct and revise. These findings are consistent with Valente et al. (2017), who reported that most teachers possess a meager understanding of models and modeling.

Teachers' Knowledge of Scientific Modeling after the Introduction of Scientific Modeling

The findings suggest that, after the introduction of scientific modeling, the participants better understood scientific modeling than before the introduction of scientific modeling activity. Even though the participants described a better understanding of scientific modeling, they did not understand all the three steps of scientific modeling, construct, evaluate and revise but described only evaluate. The interpretation in this section will begin by explaining each sub-step of evaluating the participants. These tables provide the scientific knowledge of the participants.

Evaluate. Evaluate is one of the three steps of scientific modeling the participants demonstrated while responding to the scientific modeling questions after being introduced to the scientific modeling activity. The findings suggest that the participants demonstrated the idea of evaluating scientific models after being exposed to scientific modeling activity. The findings in this study resonate with those described by Nelson & Davis (2012), who investigated the approaches and criteria the preservice elementary teachers use to evaluate elementary students' scientific models. The findings yielded that the preservice teachers developed a criteria-based approach to evaluate students' models. Therefore, this study suggests that the introduction of scientific modeling activity was critical to understanding scientific modeling.

Using. Using is a sub-step of evaluate. After introducing the scientific modeling activity, all three participants demonstrated that the knowledge of using scientific modeling is lengthy. For example, Simba incorporated the existing knowledge of scientific modeling during scientific modeling; she also described that model could be used to identify a problem, answer a question, and study a phenomenon. Chui also described the existing knowledge of scientific modeling for comparison, asking questions, and many others. In contrast, after introducing the scientific modeling activity, Nyati did not demonstrate any knowledge gained in scientific modeling. Instead, Nyati explained that scientific models are used to make explanations.

Features of Scientific Modeling. These are sub-steps of the step "evaluate." Both Simba and Chui described the understanding of the features of scientific models after the introduction of scientific modeling. In comparison, Nyati did not display any knowledge of the features of scientific modeling after the introduction of scientific modeling. This study can be linked to the findings reported by Schartz and Skjoid (2012), who revealed that teaching the nature of scientific models in science courses to prospective elementary and middle school teachers increased their understanding of scientific models to represent scientific ideas and their explanations.

Teachers' Knowledge Change of Scientific Modeling after Introducing Scientific Modeling Activity

As a result, scientific modeling has been emphasized, and its findings are noted to be working. For example, a study by Garrido and Couso (2016), who focused on developing insight on primary preservice teachers' perception of scientific practices within the teacher education course based on models and modeling, found that the preservice teachers reported that most modeling activities such as use, express, evaluate, revise models are essential while learning scientific modeling.

In this study, the three participants did improve their knowledge of scientific modeling after the scientific modeling activity. For example, Simba, Chui, and Nyati expressed their knowledge of using scientific modeling. Also, Simba and Chui demonstrated knowledge of the features of scientific modeling. These findings suggest that the participants gained knowledge of scientific modeling use, which can be ascertained based on their experiences and testimonies, such as designing experiments for their students. Also, there was substantial evidence to support knowledge gained on the features of scientific modeling. However, the participants did not demonstrate the knowledge of construct and revise steps of scientific modeling. This study revealed that even after the participants were introduced to the scientific modeling activity, they did not understand the whole process of scientific modeling and the steps involved in scientific modeling. For example, the participants lacked knowledge of the revise step of scientific modeling before and after they were introduced to the scientific modeling activity. Also, Nyati only demonstrated the uses of scientific modeling before and after the scientific modeling activity. These findings align with Davis et al. (2010), who designed instructions for the preservice teachers and argued that even with the preservice teachers being introduced to scientific modeling instructions, the preservice teachers did not improve on revise steps of scientific modeling. Also, Valente et al. (2017) asserted that the preservice teachers' understanding of models and modeling did not increase even after the teachers advanced with years in school. Therefore, due to the lack of a complete understanding of scientific modeling steps, the participants' little information about scientific modeling could hinder them from teaching in their content areas since Bennion and Davis (2021) described that, preservice teachers poorly understand scientific modeling.

It is also possible that the participants did not possess the knowledge of construct and revise because they did not understand science and its nature, which could help them understand and utilize the knowledge of scientific modeling activity they were introduced to expand their knowledge of scientific modeling. For example, Davis, Petish & Smithey (2006) asserted that new teachers do not possess the beliefs of science, such as how science is practiced, and the knowledge constructed. Therefore, it is speculated that the participants do not fully understand the beliefs of science, knowledge, and its nature.

Also, the participants could lack sufficient understanding of scientific inquiry knowledge to describe the model and explain its nature. The process of scientific modeling involves inquiry exclusively since a phenomenon is obtained from models with a theoretical focus on the structure (Belzen et al., 2019). Scientific modeling is also an approach learner engage in a scientific inquiry whose focus is on creating, evaluating, and revising scientific models that can be applied to understand and predict the natural world" (Schwarz, 2009).

Teachers' Knowledge of Model-based Inquiry (MBI)

Model-Based Inquiry (MBI) is a pedagogical approach to teaching that enables students to learn science through inquiry by engaging with scientific models following scientists (the NGSS Lead States, 2013, p.14; Oh &Oh, 2010). MBI focuses on the main concerns in science education and the teaching of authentic scientific inquiry (Baze, 2017).

A study by Windschitl & Thompson (2006) stated that with the help of designed instructions, preservice teachers could develop a deeper understanding of scientific modeling which they can use in the preparation while creating their model-based lessons. However, teachers experience challenges when implementing inquiry instructions since they lack models and adapting inquiry-based instruction materials (Dancan, Pilitsis & Piegaro, 2010).

Findings in this study suggest that all three participants exhibited the knowledge of Model-based Inquiry (MBI). However, they did not display all the four stages of MBI, but they incorporated some of them during their responses. Therefore, the interpretation in this section will begin by focusing on teachers' knowledge of MBI before the introduction of scientific modeling and will analyze each stage of MBI one by one.

Teachers' knowledge of MBI before the introduction of the Scientific Modeling Activity

This section will describe four stages of Model-Based Inquiry (MBI) that preservice teachers must demonstrate during their interviews. MBI is a pedagogical approach to teaching which enables students to learn science through inquiry by engaging students with scientific models (the NGSS Lead States, 2013, p.14; Oh & Oh, 2010).

Teacher Planning for Students Engagement. This is the first stage of MBI. Planning for student engagement is a critical element, and a solid foundation for teaching instructions because promoting students' engagement is highly regarded (Beasley, Gist & Imbeau, 2014). In addition, engagement promotes active student involvement when learning (Jang, Reeve & Deci, 2010). Therefore, students' engagement is fundamental to students' successful learning.

The findings revealed that only Simba and Nyati exhibited the ideas of teacher planning for students' engagement. For example, Simba developed the knowledge of the model to teach in a class by engaging her students with a digital model that involved students adding electrons to the model. Nyati also demonstrated that planning for hands-on activity was essential while approaching a class. However, Chui did not possess any ideas to plan for engagement.

Teacher Eliciting Students' Ideas. This is the second stage of MBI. All three participants manifested the ideas through which the teacher could elicit students. For example, Simba demonstrated using the existing knowledge of scientific modeling to develop an idea as that of crossover to build a pipe cleaner model for her class. Nyati also exhibited that the existing knowledge of scientific modeling could relate a model to the founders' effect, which led him to ask questions to understand the concept. Additionally, Chui described using the existing knowledge of models to build models and described a concept that otherwise could not be shown in the classroom. Also, Chui introduced different model types such as the mobile model, tuning folks, 3d model as it is applied in biology, and a lab of the dissected eyeball to expose body parts to students comprehending of models.

Even though the participants portrayed the ideas of teachers eliciting students' ideas, it is still unclear if the participants knew exactly how they were supposed to respond to specific individual questions, which required them to demonstrate the knowledge of teachers eliciting students' ideas since the ideas were gathered from all over their responses. These findings align with that of Thompson, Hagenah, McDonald & Barchenger (2019), which focused on secondary school science teachers who collaborated with science researchers to use scientific modeling instructions during learning and found that in the beginning, a participant struggled with the practice of eliciting students' ideas.

Teacher Supporting Students On-going Changes in Thinking. All three participants portrayed teachers' knowledge supporting students' ongoing changes in thinking. For example, Simba described that the existing knowledge of DNA could ask students questions about their prior experience with DNA. Nyati described that introducing various models could influence students' thinking about models and could be achieved by integrating the existing knowledge of scientific models. Nyati also infused a Fryer model to promote students' understanding and ask students questions about modeling. Chui stated that different models could show how things interact in graphs and the data point to show the relationship between dependent and independent variables.

Teachers and Students Pressing for Evidence-based Explanations. The findings suggest that all three participants possessed the teacher and students' ideas to press for evidence-based explanations. For example, Simba explained that asking students complex questions could enable her to identify any problem experienced by students while learning. Nyati also assessed students' critical thinking and explanations using the lab. Finally, Chui explained that he could use a model to assess students' understanding.

The participants possessed the ideas of MBI but not all of all the four stages of MBI. For example, Chui did not possess the knowledge of teachers planning for student engagement. Furthermore, even though the three participants knew about MBI, they were limited to their explanations of some stages of MBI. For example, Simba and Nyati were limited to ways through which the teacher could plan for students' engagement. Also, the participants portrayed limited ideas through which the teacher could press for evidence-based explanations. However, the three participants described with a rich explanation.

Teachers' Knowledge of Model-based Inquiry after the Introduction of Scientific Modeling

Teacher Planning for Students Engagement. All three participants demonstrated the strategies of teacher planning for students' engagement. For example, Simba planned the activity of crossover knowledge which enabled her to build a pipe cleaner model for her class. Nyati also designed students' projects to fix environmental contamination and design a mushroom project. Finally, Chui described that model helped him plan what to teach to ignite students to comprehend and retain the information of scientific modeling.

This finding relates to Juuti, Lavonen, Salonen, Salmela-Aro, Schneider & Krajcik (2021), who found that when teachers partnered with professional learning through project-based learning, they could design a more engaging lesson. Additionally, Thompson et al. (2019) who designed a study that involved teachers and science educators co-planning, co-teaching, and code briefing science units and lessons, the teachers improved their performance in which students got engaged with models of a puzzling phenomenon which enabled them to explain and stated reasons with making connections. Therefore, it suggested that the participants in this study learned about teacher planning for engagement.

Teacher Eliciting Students' Ideas. The findings depict that all three participants described different strategies that a teacher could use to elicit students' ideas. For example, Simba described the idea of allowing students to enact on miniature models and predict what those pieces of models represented, such as the Punnett square, and explaining the relationships with illegal, dominant, and recessive genes.

Nyati described that the knowledge of scientific modeling of micro-remediation could describe real-world examples, making students engaged during micro-remediation to fixing air contamination and designing students' projects such as mushrooms. Finally, Chui explained the difference between polarized and unpolarized sunglasses and described why people wear contacts and networks or glasses and networks for her students.

The findings in this study align with Harris, Phillips & Penuel (2012), who provided teachers with unit materials to support them with the ideas of eliciting students' ideas and found that teachers developed the ideas to elicit students. Also, Harris et l. (2012), who examined the teacher's instructional moves to elicit and develop students' ideas which supplemented the teachers with unit material features to support teachers elicit students in a science class, reported that teachers could readily elicit students' ideas. Additionally, studies by Thompson et al. (2019), which focused on secondary science teachers working with science educational researchers on instructional practice with scientific modeling, yielded that, teachers improved their instructional practices on teachers eliciting students' ideas. Therefore, this study indicates that the participants gained the instructional ideas of teachers eliciting students' ideas based on the ideas they demonstrated.

It is imperative and suggested that the preservice teachers always be supplemented with learning materials that will help them learn and understand what eliciting students' ideas mean and how they can prompt students to elicit their ideas.

Teacher Supporting Students' Ongoing Thinking and Analyzing Ideas. All three participants portrayed the teacher's ideas to support students' ongoing thinking and analysis. For example, Simba introduced a scientific modeling topic, explicitly described what the model entailed and its significance in learning, and asked questions considering Gregor Mendel on self-fertilization and the difference between sexual and asexual reproduction. Nyati also denoted that he allowed manipulation of models by enabling students to enable them to think harder. Finally, Chui described that model could be used for demonstration and introducing a concept and relating such concepts to students every day's life. These findings can be linked with Thompson et al. (2019), who found that secondary science teachers who worked with instructional practices with modeling improved their instructional practices of building ideas. Therefore, this study suggests that the participants gained from the scientific modeling activity, which enhanced their ideas of supporting students' ongoing changes in thinking based on their responses.

Teacher and Students Pressing for Evidence-based Explanations. The findings suggest that all three participants possessed the strategy of teacher and students pressing for evidence-based explanations. For example, Simba prompted students with open-ended questions about Gregor Mendel's self-fertilization and sexual reproduction in flowers which helped her identify misconceptions. Nyati assigned students to project-based learning, which enabled him to evaluate their understanding. Chui also explained that models enabled him to ask students to describe the relationships of force, mass, and acceleration.

This study suggests that three participants increased their knowledge of the four stages of MBI to incorporate while teaching scientific modeling. For example, they all introduced their students to scientific modeling activities. These findings align with those of Thompson et al. (2019), in which the teachers who worked with science educators through scientific inquiry instructions resulted teachers improved on ways of pressing for evidence-based explanations, which allowed students to connect and yielded model-based explanations.

Teachers' Knowledge Change of Teaching Scientific Modeling at the End of Scientific Modeling Activity

The scientific modeling activity did help the participants learn about the strategies to incorporate while teaching scientific modeling after introducing scientific modeling. Fazio, Melville & Bartley (2010) argued that preservice teachers increased their knowledge of understanding and infusing inquiry-based science teaching in a science methods course. For example, the participants were able to design activities that were never mentioned at the beginning of the scientific modeling activity. Also, the participants provided better explanations when responding to teaching scientific modeling questions, and they portrayed additional knowledge of teaching scientific modeling.

The findings from this study can be related to studies by Tanak (2020) which described, that instructional practices related to inquiry enabled the preservice teachers to develop the knowledge to design creative and reasoning-enriched activities developed by asking divergent questions and encouraging students to think, build and refine the model. Also, Schwarz (2009), who developed circles of design-based research for fostering the preservice teachers' principled reasoning in problems of practice in modeling-centered inquiry, elucidated that the preservice teachers were most likely to expand their knowledge and practices systematically. Additionally, after teachers were given the instructions for scientific modeling, they developed the PCK for scientific modeling

(Nelson & Davis, 2011; Davis et al., 2010). Also, preservice teachers who took elementary science teaching methods courses designed with modeling-based elementary science units developed pedagogical content knowledge for scientific modeling (Nelson and Davis 2011).

However, the participants were limited to understanding the ideas of teachers planning for engagement and teachers and students pressing for evidence-based explanations. This study is also supported by Davis et al. (2010), who reported that even when teachers were supported with instructions, teachers continued to hold limited views of scientific modeling while teaching students to understand scientific content. Therefore, it is unsure from the findings whether these participants understood what each stage of MBI was since none of the participants mentioned even a single stage of MBI while responding to specific interview questions.

Teachers' knowledge Changes in the Scientific Teaching Modeling and The Assignment after Being Introduced to Scientific Modeling

After the scientific modeling activity, the participants gained knowledge of scientific modeling, which enabled the participants to describe better ways with scientific modeling activities. For example, Simba described in her assignment how she would engage her students with modeling by first introducing the crossover using two X's out of pipe cleaners; one X would represent one color, the other X a different color, and the Xs would represent chromosomes.

In the assignment, Nyati described how he would model with his students about second Newton's law of motion to show the relationship between mass and acceleration.

Nyati also described how he would provide students with balls with varying amounts of sand to describe the relationship between mass and acceleration.

In the assignment, Chui described the concept of succession by providing students with a background story of wildfires news, and students were provided with individualized note cards with a name, picture, and a description and were asked to figure out the order that plants would grow back after a destructive fire that burnt everything in its path, and they described the phenomenon.

Therefore, this study suggests that the participants gained scientific modeling knowledge because they developed a detailed knowledge of the use of scientific modeling representing various phenomena and recognized the need of incorporating such scientific models in class to engage students in scientific modeling after they were introduced to scientific modeling activity since the preservice teachers shifted their ways of infusing many ideas of MBI compared to those stated at the beginning of the study. For instance, the ideas mentioned in teacher planning for students' engagement and teachers and students pressing for evidence-based explanations were developed than at the beginning, which was not mentioned. This finding relates to Juuti et al. (2021), who found that when teachers partnered with professional learning through project-based learning, they could design a more engaging lesson. In addition, Davis et al. (2010) asserted that after studying preservice teachers using instructions, they acquired the idea of incorporating scientific modeling ideas in elementary and middle schools.

Implications of the Study

The main aim of this study was to explore what the preservice science teachers know about scientific modeling and Model-based Inquiry. Therefore, to achieve the goal of the preservice teachers' complete understanding of scientific modeling and Model-based Inquiry, there is a need to prepare them with the ideal knowledge.

The study was accomplished by interviewing three participants and collecting their assignments, which implied that they gained knowledge of scientific modeling but not all the three steps of scientific modeling. For example, construct and revise were not mentioned initially and after introducing the scientific modeling activity. A study by Davis et al. (2010), who designed instructions for the preservice teachers, argued that even with the instructions, the preservice teachers did not improve on revised steps of scientific modeling. However, preservice teachers became more oriented in the inquiry after exposing them to instructional design activities after taking a second methods course (Dancan et al., 2017). Therefore, there is a need for science educators to engage the preservice teachers with multiple scientific modeling activities to prepare them and expose them to the understanding of all the steps of scientific modeling and prepare them for teaching their content area.

Also, since the literature suggests that scientific modeling is a complex topic, the preservice teachers did not have enough time to understand the scientific modeling activity. For example, a study by Capps, Crawfold & Constas (2012) reported that a more extended amount of time that emphasized inquiry during professional development allowed teachers varied opportunities to engage with inquiry and how scientists worked and had the opportunity to discuss the aspects of inquiry-based instructions in their lessons and increased their inquiry experiences for their classrooms. Therefore, it is the science educators' responsibility to allocate enough time to teach scientific modeling to enable the preservice teachers' understanding of the beliefs, knowledge of science, and its nature since the findings show that the participants did not understand the scientific modeling knowledge.

Therefore, steps of scientific modeling should be taught in one semester, and MBI to be taught in another semester to allow the preservice science teachers to learn and reflect on the science models and their application to enable them to appreciate scientific modeling. Since the less time dedicated to the preservice teachers to learn scientific modeling did not expose them to the understanding of all the scientific teaching ideas of modeling. The shorter programs offered causes the teacher to misunderstand the scientific inquiry of teaching (Capps et al., 2012). For example, Chui did not gain the knowledge of teacher planning for engagement, and maybe if he could have had a longer time, he could have improved his knowledge. This aligns with the findings of Organ-Bekiloglu & Arslan (2013) argued that after the preservice teachers completed the course of the dynamics, which involved inquiry instructions, there was no knowledge gained on inquiry.

Additionally, the preservice teachers should be engaged with scientific modeling activities to design scientific modeling lessons for their classes other than answering questions on scientific modeling since multiple opportunities with practicing and designing scientific modeling lessons will expose them to the understanding of scientific modeling and how to infuse it in their classrooms. For example, Capps et al. (2012) argued that professional development programs that offer teachers varied opportunities to engage with modeling inquiry lessons are likely to teach in their classes by engaging students with inquiry-based instructions. Also, science educators should engage the preservice teachers with technology-based models by watching them boost their modeling understanding. For example, studies by Yoo (2016) recorded that during teacher professional development, integrated simulation in modeling could enable the teachers' educators to engage teachers in modeling. It is, therefore, a responsibility for teacher educators to assign the preservice teachers with multiple scientific modeling activities that are computer-based to gain scientific modeling teaching strategies to prepare them for teaching scientific modeling.

Further, the preservice teachers should be allowed to work closely with the instructor or science educators and researchers during scientific modeling activities to promote their understanding of MBI strategies and improve their understanding of implementing such strategies in their classrooms. For example, studies by Thompson et al. (2019) described a study by which science teachers and science educators met regularly to co-plan, coteach and code brief science units and lessons, resulting in teachers shifting their instructional practices with scientific modeling with time. Therefore, the preservice teacher should be allowed to work with science educator instructors; it might expand their knowledge of infusing their classes' MBI strategies.

Limitations

This study was initially designed for undergraduate science preservice teachers, but the study was redesigned for graduate science preservice teachers since the undergraduates were unwilling to participate. Also, the study had fewer participants, possibly because the scientific modeling activity was initially designed to take place face to face, but due to the Covid-19 pandemic, the study was hindered by the fact that the participants were recruited virtually. Also, the interviews were supposed to be conducted face to face, but due to Covid 19, it was conducted virtually, which could have hindered the researcher from observing any participants' non-verbal responses.

Also, the recruitment of the participants could significantly be affected due to Covid-19, and the attrition of two participants could have potentially impacted the result. Finally, the researcher designed the scientific modeling activity. However, due to the Covid-19 pandemic, the scientific modeling activity was taught by an instructor for methods of teaching science courses, which could potentially hinder all the sections covered in the scientific modeling activity.

Future Recommendations

The scientific modeling activity and the interviews should be conducted face to face to see if the preservice teachers' knowledge of scientific modeling will change their knowledge of scientific modeling and Model-based Inquiry. Also, the study should be conducted with a more significant number of participants to see if many participants could impact the findings of this study. Additionally, since scientific modeling is a complex topic, it should be designed as a course on its own to allow the preservice teachers a significant time to learn, interact, and do research by completing varied activities to allow them to understand the details of scientific modeling and Model-based Inquiry.

Conclusion

To explore what the graduate science preservice teachers know about scientific modeling and Model-based Inquiry, the scientific modeling activity must be conducted face to face to enable the preservice teachers to interact with other fellow preservice teachers and with the instructor too, which could help expand their knowledge of scientific modeling. Also, face-to-face could allow the preservice teachers to form discussions and presentations that could enable them to gain scientific modeling knowledge. For example, a study by Yilmaz & Malone (2020) reported that in blended learning in a science methods course, the preservice teachers learning described that it hindered their learning and, therefore, preferred face-to-face learning over blended because it could allow them to communicate easily with friends the instructor and encourage them to participate more.

Additionally, the data collection should be completed face to face to enable the researcher to identify the participants' non-verbal responses when conducting interviews. Also, the recruitment of the participants should be completed face to face to allow the researcher to present the research ideas to the preservice teachers, who could convince the preservice teachers to participate in the study, which could influence the data. Further, the study should be conducted with a large group of participants for verification since this study only had three participants and was affected by the attrition of two, who could have influenced the data.

Additionally, the findings suggest that the participants improved their knowledge of scientific modeling and Model-based Inquiry after introducing scientific modeling. For example, studies by Sherman & MacDonald (2007) argued that for the preservice teachers who completed an instructional module, their science inquiry-based knowledge increased. However, in this study, not all steps of scientific modeling and stages of MBI were thoroughly described, such as teachers planning for students' engagement and teacher and students pressing for evidence-based explanations. Therefore, there are still questions such as how much time should be allocated to teaching scientific modeling?

Also, should scientific modeling and MBI all be taught in one semester, or each section be taught on its own in different semesters?

Also, since the study was initially meant for undergraduate science preservice teachers, the science educators should design a similar or related study for the undergraduate teacher to see if the undergraduate will improve on the knowledge of scientific modeling and Model-based Inquiry after the introduction of scientific modeling activity. Overall, the scientific modeling activity increased the graduate science preservice teachers' knowledge of scientific modeling and Model-based Inquiry after the introduction of scientific modeling.

Further, the study should focus on covering the instructions for the three steps of scientific modeling first in one semester to allow the preservice teachers to understand the steps of scientific modeling better. Additionally, the instructions for the knowledge of scientific modeling should also include the instructions to engage the preservice teachers with the understanding of the nature of science so that students can indulge the nature of science in understanding the steps of scientific modeling. Nevertheless, the stages of Model-based Inquiry should be covered one stage at a time to allow teachers with significant time to collaborate with their fellow to learn, identify a misconception, and correct themselves.

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