Chapter 16
Authentic Learning Experiences in Informal Science Learning: A Case Study of Singapore's Prospective Teachers

Mi Song Kim and Xiaoxuan Ye

Abstract This one-year study examines the impact of informal learning by Singapore's prospective teachers (PTs) who codeveloped an informal astronomy workshop based on a big idea of "size and distance." Drawing upon design-based research, this qualitative study collected the PTs' lesson plans, audio- or/and video-recordings of learning and teaching activities, modeling artifacts, surveys, interviews, researchers' field notes, and reflection journals. Based on an in-depth analysis of the five PTs engaging in multimodal modeling activities, their teaching practices reflected the influence of their learning experiences mediated by the workshop design principles and their expert mentor's teaching strategies. This result implies the importance of teachers' authentic learning experiences toward building this participatory learning environment.

Keywords Authentic tasks • Informal learning • Multimodal modeling • Digital storytelling

Introduction

This study aims to develop a participatory learning environment where participants are encouraged to participate in and codesign multimodal modeling activities (also known as Embodied Modeling-Mediated Activity, EMMA) that seek to facilitate not only the construction of scientific models but also the engagement of authentic inquiry rather than directed by teachers (Kim et al. 2012). Modeling-mediated learning has been proved to be a successor to constructivism and can account for students' conceptual change (Clement 2000; Lehrer and Schauble 2000; Lesh

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and Doerr 2003). Despite such affordances of multimodal modeling processes, many teachers experience difficulties in modeling-based teaching due to the lack of modeling experiences, meta-modeling knowledge, and pedagogical content knowledge on modeling instruction (Kim et al. 2011, 2012; Schwarz et al. 2009).

Multimodal modeling also implies the important role of observation that could offer opportunities for learners to recognize inconsistencies between observed experiences and their own models and hence promote inquiry, especially in the domain of astronomy. In early times, astronomy only comprised the observation and predictions of the motions of objects visible to the naked eye. From these observations, early ideas about the motions of the planets were formed, and the nature of the Sun, Moon, and the Earth in the universe was explored philosophically, which is known as the geocentric model of the universe. So authentic astronomy learning should not exclude real-world observations.

For example, for the comprehension of the Moon phases, it is essential for learners to observe at least a full cycle of the Moon phases so as to get the data and try to find a pattern as well as generate questions based upon their embodied engagement within specific contexts. Observation, whether it was made in the real-world environment (Sherrod and Wilhelm 2009; Trundle et al. 2010) or designed virtual environment (Bakas and Mikropoulos 2003), provides learners embodied experiences in an authentic learning environment. This does not only facilitate learners' conceptual learning but also enhance their motivation and interests (Kucukozer et al. 2009).

Astronomy is not taught in formal learning contexts for the youth in Singapore despite students displaying high interests in learning astronomy concepts. Hence, through building a community of learners that consists of astronomy experts from universities, science teachers, science education researchers, and astronomy amateurs, we not only hope to codesign authentic and embodied learning experiences for the learning and teaching of astronomy in informal learning settings but also to investigate effective ways to develop multimodal modeling activities in promoting participants' conceptual understanding in astronomy. The participants in our learning community, in this sense, are not merely learners with interests to learn about astronomy concepts, but also potential leaders of a broader Singapore astronomy community. They were offered with opportunities to codesign EMMA activities and perform as facilitators in informal classes organized by both the research team and the Singapore youth clubs. In this vein, we view our participants as "prospective teachers" (PTs hereafter) although they did not take up education courses in formal settings.

PTs voluntarily joined our learning community, generated interest-driven topics to explore multimodal modeling activities, and developed understandings through meaningful participation. This kind of learning echoes sociocultural perspectives that posit the learner as an active participant and not a mere passive receptacle of knowledge (Hay and Barab 2001; Kim 2012, 2013). Following these sociocultural perspectives, our research team aimed to tap benefits of informal science learning in which learning is characterized as self-motivated and voluntary, guided by not only learners' needs and interests (Dierking et al. 2003) but also collaboration and communication among learners and facilitators that are considered as the core skills for twenty-first-century learning.

Most importantly, in this informal learning environment we created, we were able to conceptualize the PTs' facilitation skills for others (e.g., workshop participants) as important evidences of their improved understanding of targeted astronomical concepts that in turn led to a deeper understanding of such phenomena (Boyer and Roth 2006). Hence, as mentioned above, we also provide the PTs with opportunities to teach. In this vein, this study specifically seeks to the influences of this learning-through-teaching approach in EMMA workshops.

Literature Review

Embodied Modeling-Mediated Activity

Drawing upon a sociocultural perspective, we adapt embodied cognition which conceptualizes that learning not only exists in the mind but in the human body as well (e.g., gesture production, manipulation of tools, mobility in a local environment, interactions with others) (Hall and Nemirovsky 2012). Hence, EMMA provides workshop participants with an embodied learning experience by engaging them in authentic observation and related follow-up modeling activities. We particularly promote multimodality in modeling activities, where participants are required to create different types of models such as a graphical model, a 3D physical model using various materials, or/and 3D computer models. Multimodal modeling activity provides abundant opportunities for students' bodily interactions with models that in turn enhance embodied cognition.

For example, students manipulate a model to reason about how different seasons come about, simultaneously using gestures to complement their explanation. By constructing and interacting with the models, students will be required to actively apply their prior knowledge and make sense of the new concept. Furthermore, it also encourages interactions that sometimes exceed the limitation of just verbal communication. For instance, some of our previous workshop participants could not distinguish the meaning of "revolve" and "rotate" scientifically, where they often end up using the words interchangeably. When using their body movement, however, they were able to articulate and distinguish the difference precisely, such as moving their hands to show how the Earth revolves around the Sun and spinning their finger to illustrate the rotation of the Earth on its axis. EMMA was shown to promote learners' understanding of astronomy concepts, such as the solar system (Kim et al. 2011), lunar libration (Kim and Lee 2013), and the Moon phases (Kim et al. 2012).

Previous studies have also shown that different modeling activities were able to provide learners with varied learning experiences and trigger different kinds of skills and sensory modalities (Blown and Bryce 2010). According to Shen and Confrey (2007), when learners try to express their improved understanding, they tend to switch from one model to another in order to better demonstrate their ideas. During this transformative modeling process, learners could progress in conceptual development.

A Big Idea of Size and Distance in Modeling

In the recent review of literature, Lelliott and Rollnick (2009) argued that the concepts of size and distance have been under-researched and under-taught, compared to other astronomy concepts such as the shape of the Earth, gravity (e.g., Vosniadou and Brewer 1992), and the Sun-Earth-Moon system (e.g., Barnett and Morran 2002; Baxter 1989). Not surprisingly, many students experienced difficulty in understanding the concepts of size and distance such as the distance between the Sun and the closest star (Sadler 1998), the scale of the Earth and the Sun, the actual size of the Earth and the Sun, the relative distance of the Earth from the Sun, the relative sizes of planets, and the relative distances between planets (Sharp and Kuerbis 2006). Some studies suggest that students' difficulty in comprehending the vast celestial distance and size lies with, firstly, the lack of life experiences they have relating to vast distances and, secondly, their misinterpretation of their observation (Bakas and Mikropoulos 2003). Lelliott and Rollnick (2009), therefore, conclude that it is important to provide students with a variety of experiences related to size and distance – in order, not only to improve students' knowledge of the spatial scales involved in astronomy but also to develop a deeper understanding of the concepts of size and distance. In that sense, our study adopted Lelliott and Rollnick's (2009) term of "big ideas" with an aim to emphasize coherence across core concepts of size and distance, rather than "themes" or "topics."

Modeling strategies have been adopted in many studies in order to improve students' conceptual change or conception formation. Kuhn et al. (2006) noted that "modeling is therefore more than reproduction: the whole process is a reflected transformation in which students actively organize their own learning. The 'subject' decides which attributes and connections out of the context are accepted, emphasized or neglected and how the results are applied to the real world" (p. 185). With an emphasis on the development of the big idea of size and distance, this study, therefore, draws specific attention to the modeling process, which involves the process of describing, explaining, representing, modifying, and developing the conceptual understanding of learners and demonstrating their learning development (Shen and Confrey 2007).

Learning Through Teaching

Some efforts have been made in previous studies to provide students with teaching experiences in terms of peer teaching, reciprocal teaching, or peer tutoring. Elmendorf (2006) noted that authentic teaching experiences promoted not only her college students' deep conceptual learning of science but also meaningful and personal connections with science. In her study, she provided her college students with an opportunity to use what they have learned in college to design a curriculum for an elementary school. It was noted that her college students learned differently when being casted in the role of teacher. For instance, they became more responsible in their own learning, became aware of their level of knowledge, and wanted to achieve deeper understanding of targeted topics. Her students also consolidated their understanding so that they were able to convey knowledge in multiple ways that in turn allowed their own students to enhance their learning experience. Hence, they eventually gained an appreciation for the learning process and became active learners.

A number of theorists have made efforts to explain how being in the teaching role is beneficial to learning from cognitive, social, emotional, and motivational aspects. The goal-oriented information processing was one possible cognitive aspect to explain the benefits as personal goal setting during learning was recognized as important for learning (Cate and Durning 2007). When preparing to teach, students determine their own goals and priorities rather than try to know what their teacher's priorities are; hence, they apply different cognitive strategies to the study materials. When teaching, students go through the process of verbalization and recitation, making cognitive connections between new concepts and their prior knowledge, which could enhance memory and learning leading to what Slavin (1996) called "cognitive elaboration." Being in a teaching role, students also need to generate questions which lead to high-quality explanation and meaningful interactions with their audience (King et al. 1998; Slavin 1996). Further, taking on students in the role of a teacher also brings social, emotional, and motivational benefits to the students (Puchner 2003). In particular, Cohen's (1986) role theory could explain the motivational benefits of being in the teaching role. When students assume the role of teachers, they also take on teachers' characteristics, self-perceptions, and attitudes that in turn allow them not only to engage in challenging conversations around complex problems but also to develop intrinsic motivation.

However, much research about student teaching experiences seems to have been shaped by the interests of improving the academic performance of students (Roscoe and Chi 2007; Streitwieser and Light 2010; Tessier 2006). Rather than such an outcome-oriented way to examine the effects of the student teaching experiences, Roscoe and Chi (2007) emphasized a process-based approach in which researchers need to examine the process of student teacher's learning and teaching experiences so as to account for their success and failure in teaching and learning. They concluded that peer tutoring could promote not only domain knowledge but also collaboration skills. By drawing on such benefits of learning by teaching, we aim to provide our PTs with an opportunity to teach astronomy through designing and implementing multimodal modeling activities in informal learning settings.

Methods

The Study

This study applies a qualitative methodology to explore learning and teaching experiences of the PTs, which is mediated by multimodal modeling activities in an informal learning setting. Our pilot studies in Singapore revealed that students and

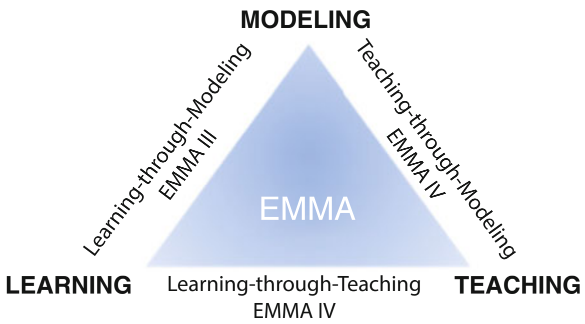

Fig. 16.1 The EMMA triangle

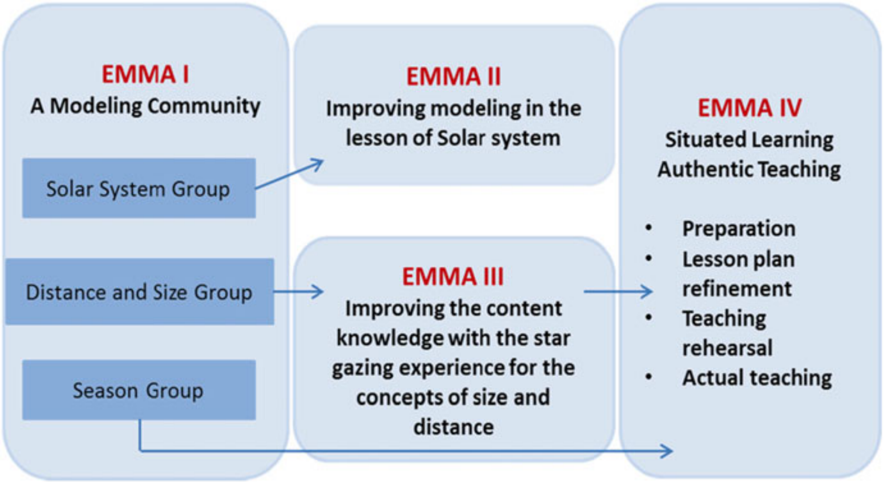

Fig. 16.2 The progress of EMMA workshops

teachers had little experience of real sky observations and modeling activities of various astronomical phenomena (Kim et al. 2011). Thus, for designing EMMA activities, design-based research has been employed to go through iterative cycles of codesigning, implementing, analyzing, and refining the EMMA activities with our research participants including the PTs. Our participants include one expert science teacher and 14 junior college students who are interested in learning and teaching astronomy in informal learning settings. In particular, we attempt to investigate the ways in which learning through teaching is mediated by multimodal modeling activities for the PTs' deep learning in astronomy. In other words, as indicated in Fig. 16.1, our intention is to integrate modeling, teaching, and learning around EMMA activities, which will be described in further details in the discussion section.

As described in Fig. 16.2, there have been four EMMA workshops for three groups of prospective teachers (PTs) before actually getting into real teaching practice involving multimodal modeling activities and lesson design activities with respect to their own chosen topics such as solar system (two male PTs), size and distance (two female PTs), and seasons (two male PTs). In EMMA I, three groups of PTs participated in a 4-day workshop across 5 weeks to explore their topics and to design lessons. For EMMA II, the initial lesson designed for solar system was refined together by the research team, the mentor, and the PTs in order to work with a new group of PTs (one male, three female JC students). In this paper, our discussion will be focused on EMMA III and IV (see Fig. 16.2), which will be introduced in the following sections.

Based upon the PTs' performance in EMMA Workshops I and II, there were four emerging objectives in EMMA Workshop III: (1) improving the accuracy of their models, using proper units of measurement and scaling, (2) understanding that the distances between celestial objects can change due to the motion of the celestial objects, (3) understanding the different methods of measuring distances and sizes of various celestial objects, and (4) using appropriate celestial objects to explain the concepts of distance and size. To achieve these objectives, the research team designed the EMMA Workshop III around authentic, embodied experiences of sky observation, multimodal modeling, and outdoor activities situated in a two-night field trip in Malaysia. The PTs were involved in observing the planetary alignment and constellations; constructing multimodal models using the fact sheet of planet properties, various modeling materials (e.g., Styrofoam balls, marbles in various sizes, play dough), and sky simulation programs (i.e., Stellarium); and measuring the distance to faraway objects in the sea. Table 16.1 describes activities and objectives for EMMA Workshop III.

Based upon such multimodal modeling experiences in EMMA III, the PTs spent 3 months to rethink the previous lesson plan they designed in EMMA I so as to revise it for implementing the lesson in EMMA IV in which they were supposed to facilitate 30 secondary school students in an astronomy camp organized by a nonprofit community center. In addition to face-to-face meetings, online communication through Facebook, phone, and e-mail allowed the PTs to revise their lesson plan in and out of the EMMA workshops.

This study examines the following questions: (1) How do the prospective teachers (PTs) develop their understandings of astronomical concepts of size and distance in EMMA workshops? (2) What affordances or benefits do learning-through-teaching opportunities bring to the PTs' engagement in EMMA workshops?

Participants

The EMMA workshops started with seven young adults (aged 17–18), and later, seven more joined. Having high interests in astronomy, they invited their friends to join our community and volunteered themselves to be facilitators (so-called prospective teachers) to conduct astronomy workshops. Participants hence came with diverse backgrounds in terms of astronomy knowledge, academic backgrounds,

Table 16.1 Activities and objective in EMMA Workshop III

Main activity	Sub-activities	Objective
Modeling of the solar system	1. Pre-workshop online discussion: PTs were asked to give comments and ask questions about the simulation-generation picture of the planetary alignment	1. Identify different planets in the sky
	2. Observation of the sky in the morning on 28 and 29 May 2011	2. Construct more accurate model to generate argument and explain phenomena
	3. Explore the sky through simulation software (Stellarium)	3. Understand relative size and distance of different planets in the solar system
	4. Modeling of the solar system on that day to explain why the geocentric argument brought by the mentor is incorrect and the planetary alignment phenomenon	
Modeling of Scorpio constellation	1. Observe the sky	1. Appreciate vast distance of celestial objects in the sky
	2. Sketch the constellations observed	2. Appreciate cultural differences in constellation in different regions
	3. Sharing talk by the mentor on cultural differences in constellation	3. Understand that the distance and size of the stars that consist constellations are varied
	4. Modeling of Scorpio constellation considering distance and size of the stars	
Measure the distance of a distant object in the field	1. Problem-solving task on how to measure the distance of a distant object without going there with compass and measuring tapes	1. Understand and appreciate the parallax methods in measuring the distance of distant objects
	2. Field practice: measuring the distance of an object in the sea	2. Improve problem-solving skills using interdisciplinary approaches
	3. Discussion with the mentor on how the method can be applied in measuring distant celestial objects	

and sky observation and modeling experiences. Their commitment to facilitating workshop participants motivated them to equip themselves with astronomy content knowledge and pedagogical knowledge, which had been facilitated by the research team members and Hong Jian (hereafter "HJ") who is an expert physics teacher with strong interests and rich content knowledge in astronomy. All names used in this paper are pseudonyms (see Table 16.2). As mentioned earlier, this paper focuses on the group of five PTs working on the concepts of "size and distance," Mei Fong (MF), Vivian, Emma, Faith, and Santhi. MF and Vivian participated in EMMA I, III, and IV, and the rest three participated in EMMA III and IV. Table 16.2 describes a brief profile of five PTs.

All the PTs grew up and have been educated in Singapore, and our survey conducted before EMMA IV revealed that there were a variety of their perceptions of learning

Table 16.2 Profile of five prospective teachers

Name	Race	Age[a]	Favorite subjects	Current status[b]
Mei Fong (MF)	Chinese	19	Chemistry	University, Material Engineering
Vivian	Chinese	19	English, Art, PE	University, Sociology
Santhi	Indian	19	Mathematics	University, Biological Engineering
Ellen	Chinese	17	Chemistry, Physics, Chinese	Junior college, grade two (equivalent to grade 11 in the USA)
Faith	Chinese	17	–	Junior college, grade two

Note: [a]when they participated in EMMA III; [b]in the year 2012

Table 16.3 Data sources and purposes in EMMA III and EMMA IV

Workshop	Data sources	Purposes
EMMA III	Video-taping of the entire process of EMMA III	Learning difficulties of PTs during solar system modeling
	Multimodal modeling artifacts (2D drawings and 3D concrete models)	PT's learning process guided by the mentor
	Pre-event survey and post-event survey on content	
EMMA IV	Versions of lesson plans since EMMA I	PTs' development on their lesson design and the development process
	Researchers' field notes on the rehearsal day	
	Pre-survey on the perception of learning and teaching, teaching through modeling, and modeling experiences	
	Video-taping of EMMA IV lesson implementation	PTs' performances including instruction to the whole class and interactions with each group
	Researchers' field notes on the actual teaching day	PTs' views on modeling-mediated teaching and their learning-through-teaching experiences
	Post-interview with PTs	

and teaching. All of them felt that EMMA workshops were beneficial to their understanding of astronomy knowledge. They often mention that EMMA workshops were different from their previous learning experiences in their schools such as "something that is beyond conventional ones," "more hands-on activities," and "a lot of modeling and have to find answers by ourselves" (from EMMA IV pre-surveys).

Data Collection and Analysis

This qualitative study collected multiple interconnected data sources as described in Table 16.3. In particular, with regard to the EMMA III video data, we have selected modeling activities such as planetary alignment since they are similar to those designed and implemented in EMMA IV by the PTs. Through the examination of the process data of both learning and teaching events, we seek to explore how the PTs will be able to connect their learning with teaching experiences.

Data collected were analyzed using a constant comparison method (Boeije 2002; Strauss and Corbin 1990). Comparisons were iteratively conducted separately within EMMA III and EMMA IV and between these two workshops for developing emerging themes. Interestingly, there were similar themes in both workshops such as “PTs’ modeling process of solar system,” “guidance and questioning from HJ,” and “argument put forward by HJ” in EMMA III and “PTs’ modeling teaching process,” “guidance to their students,” “argument put forward by PTs” in EMMA IV. These themes from open coding were then compared to that of EMMA III and EMMA IV, in order to find a relationship between the PTs’ learning and teaching experiences. Once the relationship was identified, a detailed discourse analysis was conducted. Other data sources such as researchers’ field notes, artifacts (i.e., models), and survey data were also constantly analyzed to triangulate themes generated mainly in the form of video data.

Data analysis involves three major steps. Firstly, each segment of the workshop was identified according to the modeling processes such as constructing, revising, and using models. Secondly, episodes were defined based on astronomy-related topics so as to identify not only the PTs’ learning moments but the facilitators’ facilitation as well. Whenever a new discussion topic occurred, it was defined as a new episode, and there were 20 episodes in EMMA III and seven episodes in EMMA IV. Thirdly, detailed discourse analysis was conducted on selected episodes to understand the PTs’ learning and teaching experiences. For EMMA III, we focused on the PTs’ learning difficulties and how HJ facilitated them to solve the problems; for EMMA IV, we focused on the PTs’ instructions and their interactions with the students. A total of nine episodes were selected for detailed coding.

Drawing upon Chin’s (2006) study that took place in Singapore, the unit of analysis in this paper was a move of communication (i.e., initiation, response, follow-up), as well as the types and purposes of the utterance were also considered. Compared to Chin’s research context where students mainly replied to their teacher’s questions, participants in our study took active roles and became more flexible in informal multimodal modeling activities. Hence, we emphasized the dimensions of the learning process by including not only the participants’ cognitive learning process (Anderson and Krathwohl 2001) but also the ways of how their learning was mediated.

Findings

Transforming Learning Difficulties to Teaching Moments

Although EMMA IV was the PTs’ very first teaching practice, with learning experiences facilitated by their mentor’s (HJ) expertise in EMMA III, they were able to engage the workshop participants in learning through the design of a modeling task and the generation of an argument based on real, authentic observation. They were also able to evaluate the participants' achievements by setting out certain criteria. Specifically, the PTs have effectively integrated modeling approaches into the lesson plan in three ways, with regard to the concepts of size and distance. Firstly, *they changed from lecture-oriented to a modeling-based student-centered lesson design*. In their first lesson design, they made efforts to engage students to participate in a band-making activity. However, most of the learning objectives such as the relation between distance and size were designed to be achieved by the lecture format that emphasized on content delivery. Then, after having multimodal modeling experiences in EMMA III, they had much clearer learning objectives and modeling-based activities. Secondly, their revised lesson plan demonstrated that *learning could be enhanced by the workshop participants through exploration rather than "pass-over."* In their first lesson plan, they intended to include as many YouTube videos as they could. Similarly, hands-on tasks were mainly designed for fun. Their revised lesson plan, however, aimed to address means to promote the active engagement of the workshop participants. For instance, instead of showing videos about size and distance to the workshop participants, the PTs endeavored to design multimodal modeling activities in order to engage them to construct a scaled-down model of the solar system. This allows them to calculate with varying scales of distance and size and helps them to make sense of the vast distance and understand the concepts of relative distance and size. Thirdly, *their learning activities became more situated in real-world, authentic contexts with more embedding questions*. In the final version of their lesson plan, the PTs incorporate factual knowledge of "size and distance" under authentic contexts of making the solar system and sky observation experiences in order to facilitate easier understanding for the workshop's participants.

Drawing upon these changes, in order to understand the influences of EMMA workshops in supporting a learning-through-teaching approach, we identify one claim: Learning through teaching in EMMA workshops resulted in a transformation of the PTs' learning difficulties to teaching moments that in turn led to deep learning for PTs. EMMA III provided the PTs with a sky-gazing experience which enabled them to leverage their observational experience with their learning-through-modeling experience (see Fig. 16.1). Prior to the field trip of EMMA III, HJ posted a planetary alignment picture (see Fig. 16.3) from a sky simulation software on Facebook in order not only to support the PTs' inquiry but also to promote authentic learning for them. This alignment was expected on the actual days of the field trip.

During the field trip of EMMA III, HJ intentionally created an argument that was *observationally possible*, but *scientifically unsupportable* – it was based on a geocentric model of the solar system. He used observations of stars moving across the sky (as seen from naked eyes, the telescope, and the simulation software) and planetary alignment (Fig. 16.3) in support of his argument. HJ asked the PTs to construct models to disprove his argument. Based on PTs' planetary modeling activity in EMMA III and their teaching practice in EMMA IV, we identified the PTs' two specific learning difficulties that were later transformed into effective teaching moments: (1) making both distance and size on the same scale and (2) using models to examine astronomical phenomena from different perspectives.

Fig. 16.3 Planetary alignment photo in EMMA III

Making Both Distance and Size on the Same Scale

With respect to their own model of the solar system during the EMMA Workshop III and the relation to their sky observation experiences in which all planets in the solar system were aligned, the PTs' initial model (see Fig. 16.4a) was not scientifically scaled in terms of both distance and size. For instance, Jupiter was not represented as 11 times bigger than the Earth. The PTs did not pay attention to the scale of models even though they were given a fact sheet of the planets regarding distance and size.

Hence, HJ's feedback was focused on asking questions for the PTs to think about the scales they have used for their models. The PTs' explanations about their current model were questioned by HJ, and their responses were followed by HJ's comments, feedback, or follow-up questions. HJ always referred to their models in this process, which in turn led to the PTs' modification of the models. Such an iterative process of constructing, evaluating, and modifying their own models mediated by HJ facilitated the PTs' engagement in cognitive processing such as recognizing and identifying objects, retrieving relevant information from previous experiences, inferring from known facts, and comparing different ideas and resources.

Specifically, HJ purposefully challenged the PTs to use the same scale for both the distance and size of the planets since they were struggling to appreciate the vast celestial scale. He also suggested that they should make full use of the open space to represent the appropriate distances among the planets, rather than restricting their models within a given space. After receiving such feedback from HJ, as indicated in Fig. 16.4b, the PTs revised their initial model so as to improve the accuracy of scaling.

The PTs spent a total of 3 h to calculate the scales, select the appropriate scale for size and distance, and find the appropriate objects. Eventually, they applied an

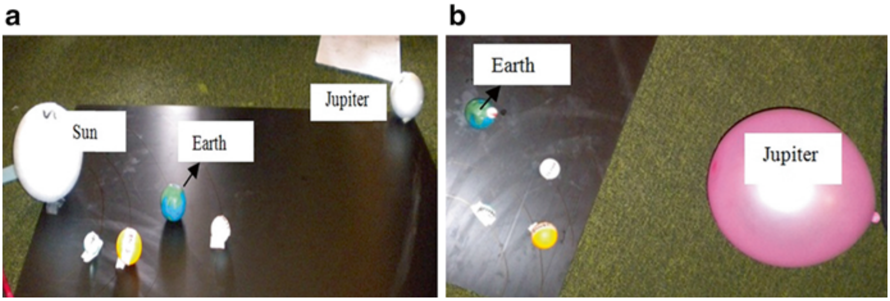

Fig. 16.4 PTs' initial and revised models in EMMA III: (**a**) PTs' initial model. (**b**) PTs' revised model

elimination strategy to take out any relatively oversized or distant objects (e.g., the Sun) in their models for constructing their own scaled-down solar system model. Regarding such learning experiences in EMMA III, Faith felt that the planetary alignment modeling activity was much more challenging than other activities because "it's very hard to find the suitable objects to represent the size… and the scale of distance and the scale of size is difficult to be combined" (30 May 2011, Interview with Faith regarding EMMA Workshop III).

Drawing upon their own learning experiences involving models in EMMA III, the PTs changed their lesson design for their actual teaching in EMMA IV. Changes include guiding of the workshop participants to construct their own 3D physical models by scaling the sizes and distances of the planets separately. In other words, by reflecting on their learning difficulties in EMMA III of using the same scale for both distance and size of the planets, the PTs aimed to avoid confusion or difficulties for the workshop participants. Furthermore, compared to the PTs' initial lesson plan designed before EMMA III, their revised lesson plan and instruction in EMMA IV were able to address the accuracy of distance and size more explicitly. For instance, they eliminated their initial idea of a band-making activity in which the workshop participants were supposed to roughly select beads in different sizes in order to represent the relative sizes of the planets, where little attention was paid to the accurate scale. Due to their own learning experiences in EMMA III, they realized the importance of scaling accuracy in constructing models and explaining phenomena such as planetary alignment.

In addition to such changes in their lesson design, the PTs actively adopted what they learned in EMMA III in order to cater for needs and difficulties of the workshop participants in EMMA IV. For instance, in the following excerpt, Santhi provided suggestions for the solar system modeling activity, such as excluding the Sun or using Plasticine to effectively make the smaller size of planets. She said:

> [To the whole class] so by watching this video, you will know that getting a scaled-down size of the Sun is impossible now, Uranus will probably be outside the classroom, so I suggest that you exclude the Sun, so maybe leave that nine planets, oh, eight planets.
>
> [To a group] Try to make good use of your materials … Make use of the Plasticine to make it of a really small size. (13 Aug 2011 in EMMA IV)

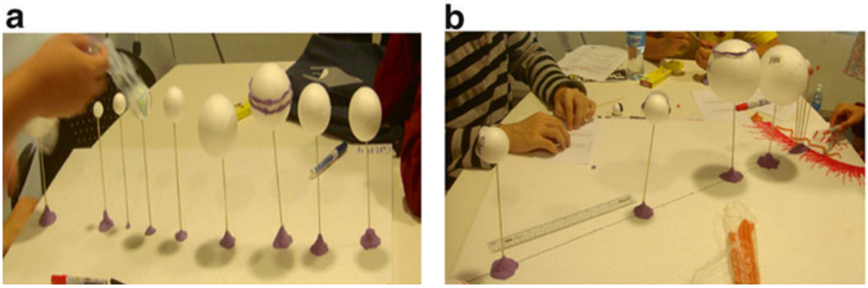

Fig. 16.5 Workshop students' initial and revised models: (**a**) Workshop students' initial model. (**b**) Workshop students' revised model

The PTs also used questioning strategies to attract the workshop participants' attention toward the accuracy of their models. For example, Faith posed a question about the accuracy of the scaled model of the solar system rather than correcting wrong scales right away, "Is this the Earth? This is the Mars? … Do you think it [the Earth] is two times of this [Mars]?" This question drew their attention to selecting proper sizes of Styrofoam balls to represent the planets. The PTs' guidance allowed the workshop participants to improve the accuracy of scaling. Compared with their initial model (see Fig. 16.5a) of arranging the planets with little attention paid to accurate scale in distance, in the revised model, they carefully calculated the relative distances between the planets. As shown in Fig. 16.5b, planets closer to the Sun were positioned closer to each other while Jupiter and Saturn were arranged further away from each other. During their presentation, the workshop participants explicitly articulated such a limitation of their model as using different scales for size and distance.

Using Models to Examine Astronomical Phenomena from Different Perspectives

In EMMA III, the PTs were given an opportunity to develop an understanding of the complex relationships and dynamics among celestial objects in 3D space in terms of examining celestial objects and events from different perspectives beyond that of the Earth (Parker and Heywood 1998). In that sense, HJ requested the PTs to construct a model to disprove his geocentric view of the solar system that explained the phenomenon of planetary alignment (see Fig. 16.3). He generated an argument by saying "you say my model is nonsense right? But my model allows me to see this (referring to the photo of all the five planets aligned in the sky) in the sky." In other words, he purposely challenged the PTs by putting forward an argument that was not only against the PTs' prior knowledge but also corresponded to their sky observation experience.

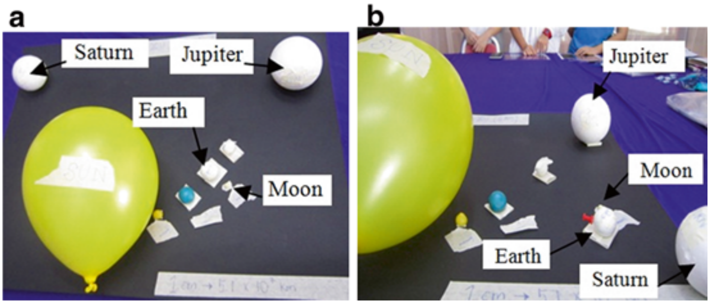

Fig. 16.6 Planetary alignment model before and after revision: (**a**) Model before revision. (**b**) Model after revision

One group of PTs (Faith, Ellen, and Vivian) initially constructed and presented their model in which Mercury, Venus, Mars, Earth, and Jupiter were arranged in a straight line (see Fig. 16.6a). They also put the Saturn randomly on the board without considering the right scale since there was not enough space on the board. Hence, the PTs mainly used their model to simply *illustrate* Fig. 16.3, rather than to argue against HJ's geocentric claims. With respect to such difficulties PTs faced, HJ used a queuing metaphor as shown in the following excerpt:

HJ: In the morning you saw Jupiter and Venus, right? And the Moon, right? It means that you are like outside the queue, right?
Ellen: Outside the queue?
HJ: You get what I mean? You have a row of people queuing for food, ok? And you see all your friends there queuing for food; then are you in the queue?
Faith: No.
HJ: No, right? You are not in the queue, right? But you look at your diagram [HJ pointed to the model]. Your Earth is in the queue, right? You get what I mean? Because you can see the queue. So my question is, are you in the queue? If you can see the queue, imagine you are buying food from the canteen and then you can see all your friends queuing up for food. My question is, are you queuing with your friends?
Faith: Not really.
Faith: No.
Vivian: No.
HJ: No, but you are telling me that you ARE in the queue!
Ellen: That [pointing to the ball representing the Earth], got to pop out. It's a bit wrong.
Ellen: Position of the Earth should be moved somewhere.
(29 May 2011 in EMMA III)

His queuing metaphor allowed the PTs to use their daily experiences to make sense of their sky observation experiences.

With respect to their sky observation experiences (see Fig. 16.3), HJ generated another argument, the so-called caveman argument, arguing that the Moon must be much bigger in size and further away from the Earth than Jupiter. Again, the PTs needed to use the model to prove HJ's argument wrong. While it was not difficult for the PTs to explain why the Moon appeared bigger than Jupiter (i.e., the Moon is closer to the Earth than Jupiter), they encountered difficulty in understanding and explaining why the Moon appeared higher than Jupiter. HJ continuously asked probing questions and guided them to use their model for explaining the observed planetary alignment as described in the following excerpt:

HJ: Firstly, you look at your pin. During sunrise, where should you be? Put your pin in the more correct position. During sunrise. Because right now I feel that you are like in the middle of the nights. [Ellen and Vivian point at different positions on the Earth. Faith changes the position of the red pin.]

Faith: Here?

HJ: Ok. So are you at sunrise now? Ok. So you can see the closest to the Sun will be Mercury followed by Venus, followed by Mars, followed by Jupiter. Then you just put your Moon in the right position. So the question is, again, are you in the queue or are you outside the queue?

Ellen and Faith: Outside.

HJ: Outside the queue. If you are outside the queue, are you able to see all the people in the queue clearly this morning? This morning.

Faith: I can see.

HJ: Yeah, you can see everybody clearly, right? So if you are able to see everybody in the queue clearly, are you very close to the queue or are you very far away from the queue?

Ellen and Faith: Far.

HJ: You should be far away from the queue right to see everybody, right? So where is Earth's position?

Faith: Further [Faith points at a spot which is further away. Ellen removes the Earth and pastes it on that spot] (see Fig. 16.6b).

…

HJ: Ah. Ok. Actually you look at this ah, and you pretend you are the pin. So you see the Sun, you see Mercury, you see Venus, you see Mars, you see Jupiter, right? Then you see the Moon, right? Ah, so all you need to do is shift the Moon a little bit.

(29 May 2011 in EMMA III)

HJ advised them to use a red pin to represent the observer's position on the Earth in the early morning when they were observing the alignment in the sky so that the PTs could imagine their perspective from the Earth in the model. This indicator helped them to examine the planets from multiple perspectives. The PTs eventually revised and modified their model and were thus able to use their model to explain why the Moon appeared higher and bigger than Jupiter. In addition, they started to become aware of positions and motions of the planets from different perspectives. The PTs also revised the position of Saturn from the Sun (see Fig. 16.6a) to the other side of the Sun (see Fig. 16.6b) so as to explain why they could observe Saturn the night before.

Based on their learning experiences in EMMA III, the PTs further employed simulating observations (see Fig. 16.7) using software in order to create an observationally possible yet scientifically unsupportable argument. The PTs requested the workshop participants to argue against it using their model as indicated in the following excerpt:

Ellen: Look at the picture, you can see that the Moon is further away from Earth because like this picture, the Moon is higher up compared to Jupiter. So I can infer that the Moon is actually further away from the Earth than Jupiter, is that true? Is that really true? (13 Aug 2011 in EMMA IV)

However, this initial introduction did not work as effectively as HJ's argumentation in EMMA III as described earlier. Many workshop participants in EMMA IV questioned why they were supposed to argue against something that was clearly

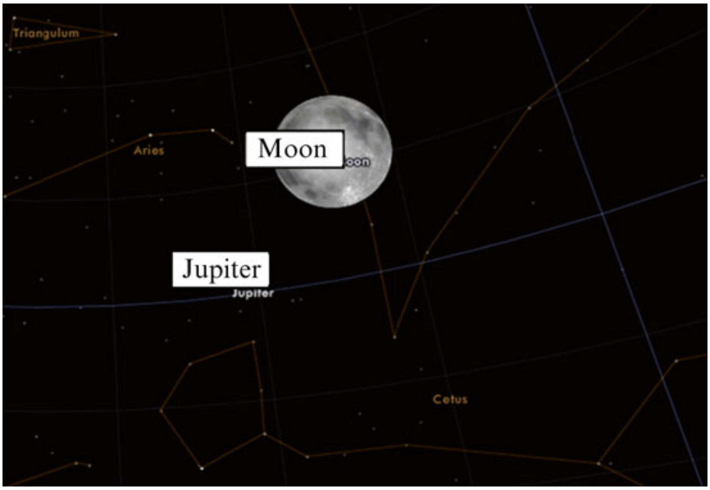

Fig. 16.7 Simulated observation picture used in EMMA IV

nonsense. One participant even asked: "If we already know the distance from Jupiter and Moon to the Earth, then what's the point of this argument?"

Facing this challenge from the participants, Santhi emphasized the use of the model in the explanation of the phenomenon. She said:

> We have a hypothesis that the Moon is further from the horizon, as you can see from the picture (Fig. 16.7), we say that the Moon is further than Jupiter, so you have to prove us wrong with the correct explanation in addition to the use of your model. (13 Aug 2011 in EMMA IV)

The workshop participants manipulated and revised their models, such as adjusting the positions of the planets so as to disprove the PTs' hypothesis. One group relied on their daily experiences in their explanation, for instance, when a big stone is thrown further away, it will appear smaller and smaller. Another group used a theory of trigonometry not only to explain how the distance of the Moon from the Earth could be calculated but also to prove that the Moon is closer to the Earth. These approaches indicate that although the PTs guided them to use their model to explain the reasoning behind the observed astronomical phenomena, the workshop participants tended to pay more attention on displaying factual information without making connections with their models explicitly.

Discussion

As shown in Fig. 16.1, in order to explore the impact of "learning through teaching" via the EMMA workshops, we have also considered both "learning through modeling" (occurring mainly in EMMA III) and "teaching through modeling" (occurring mainly in EMMA IV) with an aim to facilitate five prospective teachers (PTs) to develop a deeper understanding of the big idea of size and distance in two ways: (1) providing an authentic sky observation experience to improve the PTs' spatial knowledge and (2) offering teaching opportunities using multimodal modeling experience for reflecting on their teaching and learning experiences.

Although comparatively little research attention has been focused on the concepts of size and distance (Lelliott and Rollnick 2009), it was suggested that students who lacked observation experience posed a challenge in trying to understand it. Hence, our design-based research designed EMMA III activities (e.g., see Table 16.1) to provide our PTs with embodied experiences in outdoor environments that aimed at promoting "learning through modeling" as indicated in Fig. 16.1. For instance, the stargazing outdoor activity offered them a real-world, authentic learning setting that in turn encouraged the PTs to experience and appreciate how vast the universe is. The sizes of the planets and their distances from the Earth are not just numbers for the PTs to memorize using a fact sheet, but tools to make sense of their authentic sky observations and related astronomical phenomena. Specifically, our intention of "learning through modeling" allowed them to reflect on their sky observation experience through the construction of their own models that in turn led to improved explanatory power.

The PTs were also motivated by arguments that their mentor, HJ, intentionally created to challenge their prior knowledge (i.e., the heliocentric model of the solar system) that could not be easily explained by their authentic sky observation experiences in EMMA III. To argue against his observationally possible yet scientifically unsupportable nonsense arguments, the PTs needed to construct and use their models to prove HJ's ideas wrong through the understanding of the complex interrelationships among distances, sizes, and positions of celestial objects. This provides implications on the curriculum designs, especially in an informal learning environment where integrating observations in embodied modeling activities is considered for the PTs to visualize different perspectives and to improve spatial perception for understanding the size and distance of the 3D celestial objects.

Based on such "learning-through-modeling" experiences, the PTs effectively transformed their learning difficulties or challenges faced in EMMA III to valuable teaching moments for their workshop participants in EMMA IV. This can be referred to as "teaching through modeling" shown in Fig. 16.1. Through reflecting on their own "learning-through-modeling" experiences, the PTs endeavored to design and revise the workshop activities so that the workshop participants would face the similar learning difficulties that they had in EMMA III. The PTs also encouraged the workshop participants to construct, use, and revise their models not only by reflecting on their prior knowledge and experiences (e.g., mathematical knowledge) but also by collaborating with others.

Through such a teaching-through-modeling process, the PTs also highlighted the importance of making sense of the size and distance of the celestial objects, rather than focusing on just memorizing factual information. Hence, although EMMA IV was the PTs' very first teaching practice, the PTs had effectively integrated modeling approaches into their lesson design based on the concepts of size and distance in three ways. Firstly, they changed from lecture-oriented to a modeling-based inquiry-oriented lesson design. Secondly, their revised lesson plan implied that learning could be enhanced by the workshop participants through exploration rather than pass-over. Thirdly, the learning activities were situated in more concrete contexts. These changes showed that the PTs attempted to actively adopt what their mentors had done, especially in multimodal modeling tasks, but it is important to note that the PTs explicitly elaborated the explanatory power of modeling in their teachings as described earlier in findings. The progression in PTs' pedagogical designs of lessons implies the potential of teaching through modeling in transforming novice teachers' pedagogical orientation from traditional ways to more constructive and inquiry-based ones. In this sense, this study contributes to the professional development of science education, and future research can work on incorporation of modeling-centered teaching into science teacher education, especially for astronomy education.

Consequently, during EMMA IV, the PTs transformed their learning experiences based on the concept of size and distance into their teaching practice with an emphasis on making both size and distance on the same scale and using models to examine astronomical phenomena from different perspectives. They engaged the workshop participants through multimodal modeling activities so as to ensure learning using multiple models and to generate questions and hypotheses for explanation. Similar to our claims, some other studies (Elmendorf 2006) have also argued that students' teaching experience could facilitate their own learning process by rethinking their knowledge, reflecting on their mistakes, and maximizing their potentials. Boyer and Roth (2006) also postulated that learning is a change in the form of participation, where the participants are constitutive of the setting and they respond to and transform the resources available. In that sense, through "learning-through-teaching" experiences, the PTs transformed social and material resources not only for mediating the workshop participants' learning activities toward a deeper understanding of size and distance of the planets but also for improving their own meta-modeling, pedagogical, and content knowledge. Hence, learning through teaching is also proved to be an effective way of learning in informal contexts.

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