Chapter 10
Designing Informal Astronomy Education Toward Participatory Learning Environments

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Researchers have characterized informal science learning as self-motivated, voluntary, and guided by learners' needs and interests (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003). Further, it is strongly observational and participatory, fusing both emotional and intellectual domains, and occurring where meaning is intrinsic to context (Scribner & Cole, 1973). This finding is important and should be taken into consideration in the design and implementation of effective learning environments for learners. With the increased emphasis on informal learning, this article places particular emphasis on informal science learning and describes the stories of how to design informal astronomy workshops for Singaporean youth.

Astronomy is not provided for in formal school education for youths in Singapore, but students usually have high interests in learning astronomy concepts in many informal learning settings including families, the Science Center, museums, and communities. To provide astronomy education opportunities, our research team designed outreach programs by collaborating with a school physics teacher. In particular, we focused on designing hands-on modeling activities so-called "Multimodal Mediated Modeling Activities" (EMMA) (Kim & Lee, 2013). A growing body of literature has also demonstrated the beneficial effects of hands-on activities in science teaching and learning across formal and informal learning contexts (Schwarz & White, 2005). It is commonly recognized that teachers play a vital role in the development of hands-on model-based activities. Yet, novice teachers and even experienced teachers often face many challenges in adapting the modeling-based approach to the experience, knowledge and needs of learners (Kim & Ye, 2013). Therefore, this chapter aims to describe the stories of how to design informal EMMA workshops so as to support prospective teachers to engage in modeling-based activities.

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P.G. Patrick (ed.), *Preparing Informal Science Educators*,
DOI 10.1007/978-3-319-50398-1_10

Literature Review

Given the implicit importance of the model-based instruction literature to the development of EMMA, this section will provide Vygotskian theoretical perspectives while considering conceptual change theory that has been advocated by science educators in order to develop new learning environments. This literature review is important because these perspectives implicate radically different pathways for designing learning environments as compared to traditional science teaching and learning.

Model-based instruction in science education has focused on a radical and major reorganization of learners' prior knowledge for the acquisition of scientific concepts drawing on cognitive perspectives. From this perspective, it is argued that learning is not a way of adding new knowledge into learners' existing knowledge but a process of conceptual change. Hence, learners' conceptual change is viewed as theory change in science, which is characterized by the knowledge acquisition. Conceptual change, as researchers argued, is the use of an additive mechanism that causes a learner to add the new information into the incompatible knowledge base, leading to producing *synthetic models*, *misconception* or *alternative frameworks* (Posner, Strike, Hewson, & Gertzog, 1982), rather than the development of currently accepted, correct scientific views. As such, conceptual change researchers have made much contribution toward understanding and explaining learners' difficulties in learning astronomy behind the formation of misconceptions.

In that sense, Vosniadou's, (1994) theoretical framework, so-called 'knowledge-as-theory' with a top-down approach, becomes one of the most prominent approaches that guide research and instructional practices in astronomy education. However, her framework was also subjected to several criticisms (e.g., Caravita & Halden, 1994; Smith, diSessa, & Roschelle, 1993). It was pointed out that *alternative conceptions*, *preconceptions,* or *misconceptions* may be not as robust as it is in theory, and conceptual change is a slow and gradual process rather than a dramatic, gestalt shift happening over a short period of time. It was also argued that misconceptions are not always well-formed and/or resistant to change. By considering these critics, Vosniadou (2007) also modifies interpretation of conceptual change into *the framework theory* from *theory-like*. From this framework theory approach, the naïve, intuitive, and domain-specific theories become more focused. Naïve ideas are interpreted as resulting from the learners' everyday experiences under the influence of lay culture and needed to be changed. It is stated that "science learning does not require the replacement of 'incorrect' with 'correct' conceptions, but the ability on the part of the learner to take different points of view and understand when different conceptions are appropriate depending on the context of use" (Vosniadou, 2007, p. 10). This seems to be better congruent with constructivist emphasis on learners' prior knowledge and experience.

However, this is quite different from the sociocultural views of knowing and learning first outlined by Lev Vygotsky's theory on concept formation in two aspects: (1) *dialectical aspect of concept formation*; and (2) *activity-based concept* *formation*. First, compared to the above stated conceptual change theory influenced by constructivist perspectives, Vygotskian (1986, 1987, 1997a) perspectives draw attention to a dialectical approach to higher mental functions. For him, it is taken as important that concepts are not merely mental representation such as entities or images of some kind existing inside the head. Instead, he gave real insight into the learner's knowledge or capacity within a particular socio-cultural context rather than differentiating a world of mental objects and a world of material objects in terms of Cartesian dualism. Vygotsky argued that mental processes are not independent processes but are dependent on, subordinated to and defined in the course of changes originating in human social environments. Hence, his approach to concept formation is quite different from simply categorizing objects under certain concepts or defining a verbal definition of the concept outside the context of everyday life.

For instance, Vygotsky (1986) pointed out the genetic and dynamic relationships between spontaneous or everyday concepts and nonspontaneous or scientific concepts. He suggested that children's scientific concepts are viewed top down and their everyday concepts are viewed bottom-up (p. 102). Thus starting from opposite positions they move towards each other. For example, learners become conscious of their everyday concepts once they have acquired scientific concepts. Through integration with everyday concepts, scientific concepts as taught in formal learning contexts descend to become concrete, and unconsciously defined, performed and embedded in everyday practices. However, although Vygotsky classified scientific concepts learned in formal education system in order to compare them with spontaneous everyday concepts acquired in everyday life, he viewed the two types of concepts as parts of an essentially unitary process. He therefore stressed the important role of teachers who need to explicitly integrate a student's subjective experience and personal knowledge of everyday concrete events with conceptual knowledge in communities of domain-related practices (van der Veer and Valsiner, 1991).

Secondly, unlike traditional experimental psychology, Vygotsky suggested that lower natural mental processes could be transformed into higher or cultural psychological functions through the mediation of words and other semiotic tools. As such, he characterized the process of concept formation as mediated activities by semiotic tools, rather than by the immediacy of intellectual processes. In particular, Vygotsky addressed a dialectical process of interconnecting the senses and perception with knowledge and truth, which tend to be viewed as independent entities. Although he focused on the role of semiotic tools, in particular the function of language, Vygotsky (1978) also regarded make-believe play, drawings, movements, mathematics, and arts as important tools for supporting learners' unique and idiosyncratic sense making towards the development of concept formation (Kim, 2011).

Compared to Vygotsky's well-known meaning making processes, his notion of sense making receives less attention. Meaning is the most stable and precise zone of several dynamic, fluid, and complex zones of sense (Vygotsky, 1986, 1997a). *Sense* refers to the whole set of psychological events elicited by a word in terms of activities, impressions, and personal meanings. His notion of inner speech indicates also the importance of sense-making for constructing concept formation. Inner speech is more mediated by the personal emotionally charged sense of *words* or *concepts* rather than by the common understandings of the sociocultural meanings of words or concepts. Since words acquire sense from the contexts in which they occur, inner speech is not intelligible without context. Vygotsky (1987) used this concept of sense to explain the internalization process through which sense develops in the individual's system of meaning and is developed by sociocultural meanings.

These interrelated aspects of meaning suggest the need for a reconsideration of socioculturally mediated concept formation. Vygotsky addressed the important role of social interactions in sociocultural contexts in developing higher mental functions through the appropriation of semiotic tools or what Vygotsky (1978, 1997a) called 'psychological tools' including extra-linguistic tools (e.g., drawing, movement, works of art, music, numeracy). Consequently, these Vygotskian perspectives on concept formation allow a better understanding of the participatory learning environments whereby learners are considered as active knowledge constructors through participating in authentic activities. Drawing on these Vygotskian perspectives on concept formation, this chapter will examine the design principles of the EMMA workshops working with diverse populations in informal multiple settings so as to promote their deeper conceptual development of astronomical phenomena in a participatory learning environment.

The Study

Over the course of two years, our research team has developed the EMMA workshops across different contexts working with diverse population who have interests in astronomy with an aim to create opportunities for them not only to learn astronomy phenomena but also to teach the astronomy related topics to others, especially within informal educational settings (Kim, Lee, & Ye, 2012a). This EMMA workshop views the workshop participants as both teachers and students of astronomy.

Setting and Participants

Starting from 2009, the research team conducted four workshops in the pilot study phase with the focus to explore the relationship between the interconnected elements among modeling, observation, and concepts as shown in Fig. 10.1. These four workshops were designed not only to promote workshop participants' interests

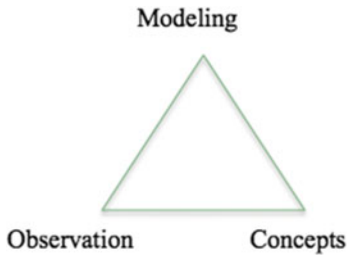


Fig. 10.1 Interrelationship among observation-modeling-concept formation

in astronomy but also to explore design features that could guide subsequent EMMA workshops toward developing a participatory learning environment.

Table 10.1 describes each of the EMMA workshops including participants, sites, and duration as well as the main theme.

Four workshops were conducted such as EMMA I with the school astronomy club students (15–17 years old) at a local junior college, EMMA II with 4 primary school teachers and the school astronomy club students at a local junior college (15–17 years old), EMMA III with 15 children with special needs (aged 7–14 years old) at the primary school, and EMMA IV with 22 secondary school students (13–15 years old).

Table 10.1 Settings and participants in the EMMA workshops

Workshops	Site	Number of participants	Duration	The main theme	Models
EMMA workshop I	Malaysia	10 local junior college students (15–17 years old)	Two nights, 3 days astronomy camp in 2009	Solar System	2D drawings, 3D physical models
EMMA workshop II	Malaysia	2 student facilitators, 11 local junior college students (15–17 years old) of astronomy club, 4 primary school teachers	Two nights, 3 days astronomy camp in 2010	Solar System	2D drawings, 3D physical models
EMMA workshop III	Singapore	15 children with special needs (aged 7–14 years old) at the primary school	1 day in 2010	Day and Night	2D drawings, 3D physical models, Role-playing
EMMA workshop IV	Singapore	22 secondary school students (13–15 years old)	2 days and half day in 2010	Moon Phases	2D drawings, 3D physical models, 3D computer models

Data Collection & Analysis

The overall research project adopts a design-based research (DBR) approach to create the EMMA workshops through cycles of co-designing, implementing, analyzing, and refining the EMMA workshops with the participants (Barab & Squire, 2004; Brown, 1992). The main purpose of this chapter is to explore design principles that enhance the effectiveness of the EMMA workshops toward a participatory learning environment. Through four separate EMMA workshops taking place across multiple sites with diverse population (see Table 10.1), this chapter will examine the main design progression across the EMMA workshops that characterize the overall nature of the design principles toward participatory learning environments. For the in-depth understanding of the learning process among the participants, multiple interconnected data sources were collected such as the participants' paper-and-pencil pre- and post-survey regarding the workshop theme, video- and audio-taping of the workshop, artifacts, interviews, Facebook posts, and the researchers' reflective journal. Detailed information about each workshop can be found in other articles (Kim, Lee, & Kim, 2011; Kim, Lee, & Ye, 2012b). Specifically, this article employs a narrative research (Clandinin & Connelly, 2000). Hence, after collecting detailed stories of each workshop, I reorganized and rewrote the stories within a chronological sequence (Ollerenshaw & Creswell, 2002) for "organizing episodes, actions and accounts of actions" (Sarbin, 1986, p. 9). Using the constant comparative method (Strauss & Corbin, 1990), empirical findings of each workshop were also compared with the overall EMMA workshop goals and outcomes.

Once audio- and video-recordings of each workshop were transcribed, three researchers independently went through these transcripts while connecting with other relevant data sources. Drawing upon such individual interpretations and emerging evidences, in order to reach a consensus about identifying and defining the main design procession of the EMMA workshops, all three researchers engaged in communication, argumentation, negotiation, clarification and identification of the design progresses in terms of dynamic interrelationships among the workshop design objectives, the workshop results, and the workshop reflection for improvements. This data analysis also focused on making sense of how to make a connection among the successes and challenges across the EMMA workshops.

Findings

As described in Fig. 10.1, the interrelationship among observation-modeling-concept formation was addressed so as to explore how authentic observation experiences could be integrated in multimodal modeling activities for promoting the participants' concept formation. Table 10.2 summarizes these workshop objectives, outcomes and reflections.

Table 10.2 The Summary of the EMMA workshops

Workshop	Objectives	Results	Reflection for improvements
EMMAI	• Integrating observation-based modeling for concept formation • Exploring affordances of modeling	• The workshop participants represented their prior knowledge (e.g., size and order of planets in the solar system) when they constructed a model • Sky observation stimulated the participants to integrate new celestial objects into their initial model (e.g., male group: Inserting a star chart in their model; female group: revisiting their observation experience to identify the position of their constellation) • Some participants made cultural association and aesthetic representation in their models (e.g., angel for representing virgo constellation) • Multiple models provide collaborative learning within and between groups • Model modification required scaffolding from facilitators. • Most participants needed inquiry learning skill to explore and improve models • Weak connections between observation and modeling • Insufficient guidance for facilitating observation, modeling and concept formation	• To explore facilitator scaffolding strategies • To conduct a literature review about affordances of models • To improve the connection between sky observation and modeling
EMMAII	• Integrating observation with modeling • Incorporating modeling evaluation and revision • Investigating the roles of student facilitators and main facilitators • Investigate how teachers learn through modeling	• The workshop participants talked about their prior knowledge about stars, planets, and tilted plane of the Earth while constructing the model • The workshop participants had difficulty to build explanatory models of the solar system initially • Student facilitators played the roles to facilitate the workshop participants to build a model to connect their solar system knowledge and night-sky observation • A main facilitator (HJ) developed an argumentative approach by posing a scenario-based question to bridge the gap between modeling and observation • Teacher participants constructed their model by	• To improve instructional design for allowing the workshop participants to engage in observation-based inquiry and to develop an explanatory model beyond an illustrative model • To establish an astronomy community to support modeling experience in learning and teaching astronomy-related topics

(continued)

Table 10.2 (continued)

Workshop	Objectives	Results	Reflection for improvements
		relying on authoritative sources (e.g., their knowledgeable colleagues, reference books or the owner of the material shop) under lack of inquiry skills to explore their own models • Teachers did not incorporate their night-sky observation experiences in modeling. • The workshop participants recognized the limitation of their model	
EMMAIII	• Integrating observation with modeling • Developing multimodal modeling including ICT-integrated storytelling • Allowing young children with special needs to understand better concepts of day and night • Providing them with their first multimodal modeling experience	• Developing multimodal modeling teaching and learning: Multimodal modeling activities (audio, visual and kinesthetic modality) such as 2D drawing, ICT-integrated storytelling and role-playing were employed to anchor their interests and experiences to explore concepts of day and night • Understanding young children's prior experiences and perceptions about day and night: They enjoyed multimodal modeling activities including moon and saturn observation and role-playing • 50% of students explained occurrence of day and night drawing upon motion of celestial objects • Connection between activities was still weak • Observation makes learners engaged and facilitates their interests	• To improve the connection between sky observation and modeling • To improve the connection among activities • To co-design lesson with school teachers to better understand their students' experiences, knowledge and interests
EMMAIV	• Integrating observation with modeling • Developing interdisciplinary activities • Exploring a guidance for modeling from illustrative to explanatory models • Exploring students' understanding of the moon phases	• Developing interdisciplinary modeling lessons for "moon phases and moons of jupiter" • Constructing, evaluating, and modifying models are key learning activities • The modeling process allows the participants to engage in discussion to clarify their models. This allows them to change their perspectives • Participants were able to understand and explain the position of new moon and full moon through modeling	• To improve the connection between sky observation and modeling: The topic of moon phases need long term observation • To improve the connection among activities • To co-design lesson with school teachers to better understand their students' experiences, knowledge and interests

(continued)

Table 10.2 (continued)

Workshop	Objectives	Results	Reflection for improvements
		• Multimodal models afforded the workshop participants to explore different concepts of the moon phases (e.g., 2D drawing to discuss about the sequence of moon phases; 3D concrete model with a light bulb to indentify the positions of the new and full moons; 3D software to demonstrate the tilted plane of the Moon's orbit) • Facilitation is important to highlight participants' contradictory ideas, which in turn motivate them to prove their argumentations	

EMMA Workshop I

A two-night three-day astronomy camp in 2009 was designed to support the participants' solar system concept formation through night sky observation and their collaborative construction of models (Kim et al., 2011). In the workshop, there were ten Singapore junior college students belonging to the school astronomy club with high interests in learning astronomy. Night sky observation in Malaysia was arranged for them to observe stars and planets and become motivated to model them using 2D drawing and 3D physical models. Their school teacher named HJ (pseudonym) guided and facilitated the workshop activities as a result of the collaboration with the research team. As an expert physics teacher, HJ had won teaching awards locally and he himself enjoyed and recommended strongly sky observation in understanding and exploring astronomical phenomena. As such, the research team with HJ explored and predicted upcoming sky conditions during the workshop using computer-based models (e.g., Saturn at about 8 pm; Milky Way from 8 pm onwards; Mars, Jupiter and Neptune at about 5 am) so as to encourage the participants to make a connection between sky observations of certain astronomical phenomena and modeling activities. For instance, multiple materials such as polystyrene balls, sticks, wires, papers, star chart, cotton wool, cardboards etc. were prepared for the participants to make their own decisions on which materials were appropriate for modeling night-sky observations.

There were two groups because the participants preferred splitting into groups with their respective genders. Interestingly, the ways of modeling of the night-sky observation were different between groups. A group of males did not spend sufficient time discussing what they observed. Instead, they put more efforts to display mainly their prior knowledge of the solar system to come up with their model. Below is the excerpt that showed their main focus and emphasis on factual knowledge about the planets in the solar system rather than incorporating their sky observation experiences. Figure 10.2 also shows that although they observed the

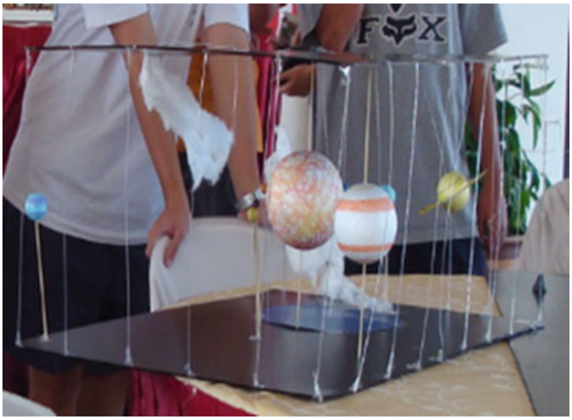


Fig. 10.2 The male group's night sky model

sky from the Earth, by drawing on their factual knowledge, they constructed their model from a top view perspective of the solar system representing the entire solar system with an emphasis on the accuracy of representing interesting properties, colors, shapes, sizes and distances of each planet (e.g., the red dot of Jupiter, the ring of Saturn, the tilted Earth).

M4: Mars a bit too small
(*M3 compared the size of Mars with other planets*.)
M2: No, Mars is nice.
M2: It's just bigger than Mercury and smaller than earth.
M2: Wait, that's not Venus, that's smaller…
M2: Shouldn't it be smaller than this?
M3: That's Venus.
(*Students agreed with the size of Mars after comparison*.)
M1: (Do) you want to do Jupiter or not?
M3: I will be doing it.
M1: You want to do Jupiter. Let's color brown stripes.

On the other hand, compared to the male group, the female group was very much based on their own experiences with the night-sky observation. They discussed among group members about where the stars were around a certain time and wanted to build their model to show their knowledge and experiences about the night-sky observations. In this process, the female participants tried to reflect on their prior knowledge, daily experiences, night-sky observation experiences on a previous night, and interpretation. As shown in Fig. 10.3, they constructed the night sky model as seen from the Earth perspective, including only what they observed. However, they were more artistically inclined so that they spent much time on discussing artistic aspects (see Fig. 10.3).

This result shows that it is not easy for the participants to integrate their concrete observation experiences with their modeling activities towards understanding and

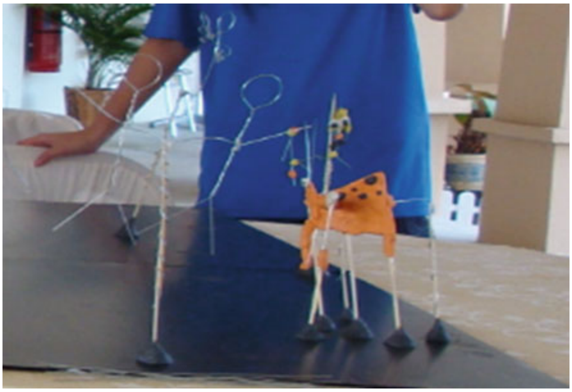


Fig. 10.3 Modeling the night sky in the female group

exploring why celestial objects appeared the way they saw on the sky. They just attempted to "arrange [the model] such as more like what we saw last night" (Interview with one student, March 2009). With respect to such a modeling approach, the research team including HJ tried to carefully observe and listen to what they did, expressed, told, constructed, and questioned. This careful listening allowed HJ to highlight and consolidate similarities and differences between two groups rather than simply pointing out the correct model. Eventually, the female group came up with the idea of merging those two very different modeling approaches. The male group also agreed with the idea of merging two models and started to discuss how to merge them. This emergent idea indicates that two groups became more open-minded and were willing to revise their models by communicating and integrating new ideas.

EMMA Workshop II

The integration of concrete observation experiences into modeling activities also became the most important part of the EMMA Workshop II. Similar to the EMMA Workshop I, there were also junior college astronomy club members who were all new members except two senior members. They worked as facilitators in the EMMA Workshop II to guide their junior students based on their previous experience in the EMMA Workshop I. Additionally, there were four primary science teachers who were supposed to explore how to involve their students in learning activities using a telescope recently purchased at their school. Despite having their science background, teacher participants tended to endeavor to look for one correct idea or answer when they constructed their model in relation to their night-sky observations. For instance, before arriving at the workshop without having observation experiences, they had already decided on a full set of modeling materials, astronomy reference books, and a star chart. Further, during the modeling activity, they mainly followed the direction of one male teacher with more of a physics

Fig. 10.4 Modeling the night sky in the teachers' group

background, rather than attempting to arrive at their own understanding and explaining of target astronomical phenomena. Hence, while constructing their model, teacher participants did not pay more attention to exploring how a phenomenon occurred at the night-sky. Figure 10.4 shows their model of the solar system, which mainly exhibited information that was recognized as a scientifically accepting fact by authoritative sources such as their knowledgeable colleague(s), reference books, or the owner of the material shop.

Hence, compared to student participants, teacher participants did not incorporate their own interpretations, experiences, and impressions related to night-sky observations and the modeling activities. For example, HJ pointed out that their initial model did not explain why they could observe the rings of Saturn and Milky Way from a particular direction in the sky at a particular location and time though they could not see the Moon. However, although the other group of students tended to communicate their understanding of the target phenomenon through reflecting upon their night-sky observation experiences or evidences, it was not obvious that they used their model to explain how observed phenomena occurred.

In order to cater to such learning needs of the participants, HJ played an important role of not criticizing but valuing, accepting and challenging their models. Specifically, there were two important instructional strategies HJ implemented based on close collaboration with the research team and his own learning and teaching experiences involving modeling activities. First of all, HJ explicitly addressed the importance of remodeling processes whereby the participants had an opportunity to make connections between their own sky observation experiences and the model construction. Similar to the previous workshop, he encouraged the participants to revise their models based on information from their night-sky observation experiences. Secondly, in relation to the EMMA processes, HJ started to emphasize and develop an argumentative approach by posing a scenario-based question, asking the participants to imagine themselves in a situation in which they were supposed to prove and explain their ideas or argumentations using models they constructed to persuade others (e.g., young children) who were assumed to be with little knowledge of science.

EMMA Workshop III

The subsequent two workshops also continuously attempted to develop the use of modeling so as to encourage the participants' engagement towards promoting concept formation in astronomy. In particular, with an aim to better support the participants' modeling experiences, *interdisciplinary approaches* and *multimodal modeling* were incorporated so as to emphasize the active participation of the workshop participants in authentic practices by integrating across domains using various forms of representations. Compared to the previous two EMMA workshops occurring in Malaysia, two workshops with the Scout Camp and the Science Club took place within Singapore because the participants were relatively young with special needs. By taking the interdisciplinary multimodality modeling approach, the research team came up with an authentic theme for the workshop with respect to the participants' expectations, experiences, challenges, and abilities. For the Scout Camp workshop, the theme of "Day and Night" was selected, because these were not only the daily astronomical phenomena for them, but were also recognized as one of the fundamental astronomical concepts (Lelliott & Rollnick, 2009). Further, the astronomy simulation software (e.g., Stellarium) predicted that the participants could observe the moon during the workshop so that it was possible for them to get an embodied, authentic, and concrete experience.

With an emphasis on contextualization and visualization of astronomical phenomena so as to connect with the children's prior knowledge and experiences, the ICT-integrated storytelling activities were designed and implemented. Rather than telling simply a scientific explanation about the cause of day and night, the research team helped the children with special needs experience a variety of stories with respect to the cause of day and night across different cultures. Following the storytelling activity, the children with special needs were grouped for communicating and sharing their ideas, thoughts and questions about day and night using a 2D drawing, 3D researcher-created physical scale models, human modeling as well as observing the Moon and the Moons of Jupiter through their naked eyes and a telescope offered by volunteers from amateur astronomy clubs. The children were encouraged to think about the cause of day and night by considering such guided questions as 'Why do we have day and night?', 'How do day and night occur?', 'What causes day and night?', 'What do you see at the day time or night time?', 'Does your moon/sun/earth move?', 'How does the moon/sun/earth move?', 'Where is the sun at night?', or 'Where is the moon at day?'. This indicated the affordance of involving the children with special needs in such multimodal modeling activities for activating their prior knowledge and daily experiences, encouraging them to describe, explain and make sense of their observation experiences and promoting their abilities to contextualize and visualize conceptions about day and night as well as to reason day and night formation.

EMMA Workshop IV

Further, for the Science Club workshop working with 22 secondary school students (aged 12–15), the theme of the "moon phases" was chosen because it was expected to observe the crescent Moon and Jupiter as well as four largest and brightest moons of Jupiter at the workshop (Kim et al., 2012b). Table 10.3 shows various activities designed in the EMMA Workshop IV.

The workshop activities were aimed to develop and implement multimodal modeling and interdisciplinary approaches towards promoting the participants' concept formation and deeper learning about the Moon Phases. According to Lelliott and Rollnick (2009), most of students are unable to explain why the phases occur or to develop a coherent understanding of the phenomenon. Hence, the

Table 10.3 The activities in the EMMA workshop IV

Activities	The EMMA process
Day 1	
2D drawing about the moon phases	Activating the participants' prior knowledge and experiences and simulating observation-based questions regarding the moon phases
Questions about the astronomy and physical astronomy concept mapping	Engaging the participants in observation-based inquiry; Constructing a physical astronomy concept mapping
Making a telescope	Hands-on activity: building a model of a telescope to experience, experiment, use and understand the concepts of telescope design and lenses
Sky observation using an astronomical observation software (e.g., Stellarium): moon and jupiter	Sky observation & exploration
Making a poster about "Tour to jupiter moons" and poster presentation	Engaging the participants in observation-based inquiry about the expedition to the space; exploration to new information about the moons of jupiter
Sky observation using a telescope: moon and jupiter	Sky observation and exploration
Day 2	
Playing a word game	Playing a word game to use key vocabularies in relation to the moon phases
Modeling of the moon-earth-sun system	Modeling and generating argumentations about the moon phases
Making a crater	Hands-on activity: Observing and exploring the formation of different types of craters on the sand surface using different sizes, shapes and materials of objects
Sky observation: moon	Observation and exploration

modeling activity was designed to develop inquiry skills among the participants who were supposed to explain how the Moon moves and why the moon phases occur by their 2D drawings and 3D physical models of the moon phases.

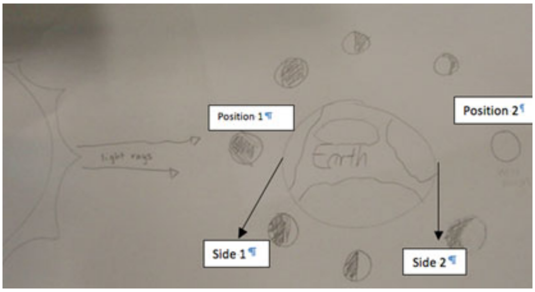
Similar to the teacher participants in the previous workshop, the students tended to rely on authoritative resources such as more knowledgeable peers or information using their mobile phones. While constructing models, each group encountered contradictions to explain the cause of the moon phases. Initially contradictions among group members were less obvious because they were more apt to ignore their contradictions engendered by different ideas or explanations. However, through being engaged in careful listening, as noted earlier, HJ respected and accentuated different ideas and explanations among the participants' ideas about the moon phases within a group.

For example, in the following excerpt, 14 year-old Jane mentioned that at the position of Moon-Earth-Sun (see Position 2 in Fig. 10.5), the Moon is a new moon because "the Earth blocks the light" whereas 14 year-old Alice addressed that at the position of Earth-Moon-Sun (see Position 1 in Fig. 10.5), the Moon is a new moon because the surface of the Moon that faces the Earth "does not get any light".

Interestingly, despite being apparently different argumentations about the new moon phase in relation to the Sun and Earth, both Jane's idea (Position 2 is the new moon which she cannot see at night, see turn 3, turn 5) and Alice's idea (at Position 2, she can see the Moon at night, see turn 7) were accepted by HJ as correct: "I'm saying that what you [Alice] are saying is correct and what you [Jane] are saying is correct" (see turn 14). Hence, HJ intentionally repeated and clarified the participants' descriptions, explanations and reasoning so as to reach a consensus between two contradictory argumentations.

HJ attempted to encourage the participants not only to express and share their own different, even contradictory ideas but also to listen to and respect other participants' ideas, which led him and the participants to understand and integrate such contradictory ideas as important and interesting argumentations. This ability to develop and create argumentations based on the participants' contradictory ideas, therefore, allowed HJ to guide them to discuss and argue on critically the concept of the causes of the moon phases to defend their own argumentations (see turn 19). HJ also provided emotional support to avoid the participants' frustration and encourage them to continue their discussion and exploration.

Drawing upon his own learning experiences with the research team, HJ further leveraged affordances of multimodal modeling such as contextualizing astronomical phenomena by utilizing 3D astronomy software, requesting the participants to verbally describe their visual representation to make sense of their 2D drawing (see turn 1, turn 4, turn 6, turn 8, turn 10, turn 12 and turn 14), and encouraging them to construct 3D physical models to find out evidences to support and explain their own argumentations (see turn 19). With respect to the moon phase modeling activities, HJ noticed the limitation of 2D drawing in terms of representing the concept of the inclination of the Moon's orbit. Therefore, he encouraged the students to build 3D physical models to find evidences to support their argumentations. As shown in the photographs in Fig. 10.6a 3D model provided the participants with better visual



01	HJ	See ah. Here (position 2) you (Jane) say no moon right. Cannot see the moon right? So here (position 1) you say can see the moon?
02	Alice	Here can see the moon?
03	Jane	Here (position 2) is the moon what. This is the new moon. New moon means no moon.
04	HJ	So how? So you see.
05	Jane	There no moon what. It is written down there for you.
06	HJ	So can see the moon here or here?
07	Alice	There (position 2).
08	HJ	Now at night where are you?
09	Alice	Centre
10	HJ	Huh? We stay at the centre of Earth ah? On the surface of Earth, right?
11	Jane	At night there [point to the side 2] la. Morning here [point to the side 1] la. Morning got light.
12	HJ	So at night you [Jane] are here (side 2). Can I see the moon?
13	Alice	Can.
14	HJ	You [Alice] say 'Can' just now. Just now you [Jane] say 'Cannot'? So you see the contradiction. Ah! I want you to see the contradiction. Okay I am going to tell you a scary answer. I just told them and they got stressed out. I'm saying that what you [Alice] are saying is correct and what you [Jane] are saying is correct.
15	Alice	huh?
16	HJ	Correct! The Earth blocked the light from the Sun then cannot see the moon (at position 2). But I'm telling you that, at night you are here [pointing to the side 2] right, so you can see the moon (pointing at position 2). Right? You are also correct.
17	Jane	So there is still moon, you just cannot see only.
18	Alice	How come?
19	HJ	Ah! you want to see all these points, (so) you build first and then see for yourself. Ah okay. Start doing the building one. And then you must start looking at it and why what you say is correct, and what you said is also correct. Wah so confusing, Right? Funny right? I purposely want you to challenge each other. But actually both are correct. But later on I show you, you say ah… both are correct. Okay.

Fig. 10.5 The moon phases

affordances, where they created actual light rays by using a light bulb and manipulated their model by changing a position to simulate the dynamic system.

The following excerpt indicates that Jane productively engaged in constructing a 3D model and used her group's model to explain the moon phases. Initially using her group's 2D drawing model, Jane put more emphasis on illustrating the moon phases by simply naming each moon phase. This was challenged by HJ who attempted to motive her to use the model not only to illustrate but also to *explain*, *show*, *or demonstrate* her idea in relation to the moon phases, in particular the new moon phase (see turn 20, turn 28). Jane took an action to life up the bulb to demonstrate how the Sun is big enough to shed to the surface of the Moon at the Position 2, which she initially named as the new moon (see turn 3).

20	HJ	Okay don't worry. Just say. The basic questions. When is the first day, when is the fifteen day? How come you can see the moon, how come you cannot see the moon? Ah explain.
21	Jane	You don't know what we are laughing about. Never mind. This is the first day [point to position 1]; this is the fifteen day [point to position 2].
22	HJ	Okay. When can you see the moon? Full moon?
23	Jane	Here. [Point to position 2]
24	HJ	Why?
25	Jane	Because the sun is big.
26	HJ	Ah. Because the sun is big. Therefore what? What happened?
27	Jane	Therefore can see the moon.
28	HJ	How to see? You show me how to see?
29	Jane	There. [Jane lifted up the bulb so that the light can shed to the surface of the moon at position 2]
30	HJ	Oh. So you see the moon is now bright is it?
31	Jane	Yes. Here cannot see because it is blocked. [Point at position 1]
32	HJ	Here cannot see because it is blocked?
33	Jane	The Sun only shines here. The light is only here, this part, at the back only.
34	HJ	Ah one side only. Then we cannot see. Okay.

Hence, Jane's modeling activity indicates how she productively changed from an illustrative model to an explanatory model, and developed increasingly sophisticated views of the explanatory nature of models. She started to make connections between the moon phases as seen from the Earth and the relative position of the Sun, Earth and Moon. As such, this modeling practice shows that HJ and the research team used constructing a model as a way to generate contradictions from the workshop participants' multiple ideas, experiences, or beliefs in relation to a target phenomenon (e.g., the moon phases). The modeling practice motivated them to engage in modeling practice to look for more concrete evidence from the model to explain and prove their argumentations for both themselves and others.

As an important part of consolidation to resolve contradictions and reframe solutions into a more in-depth question, the participants were also supposed to

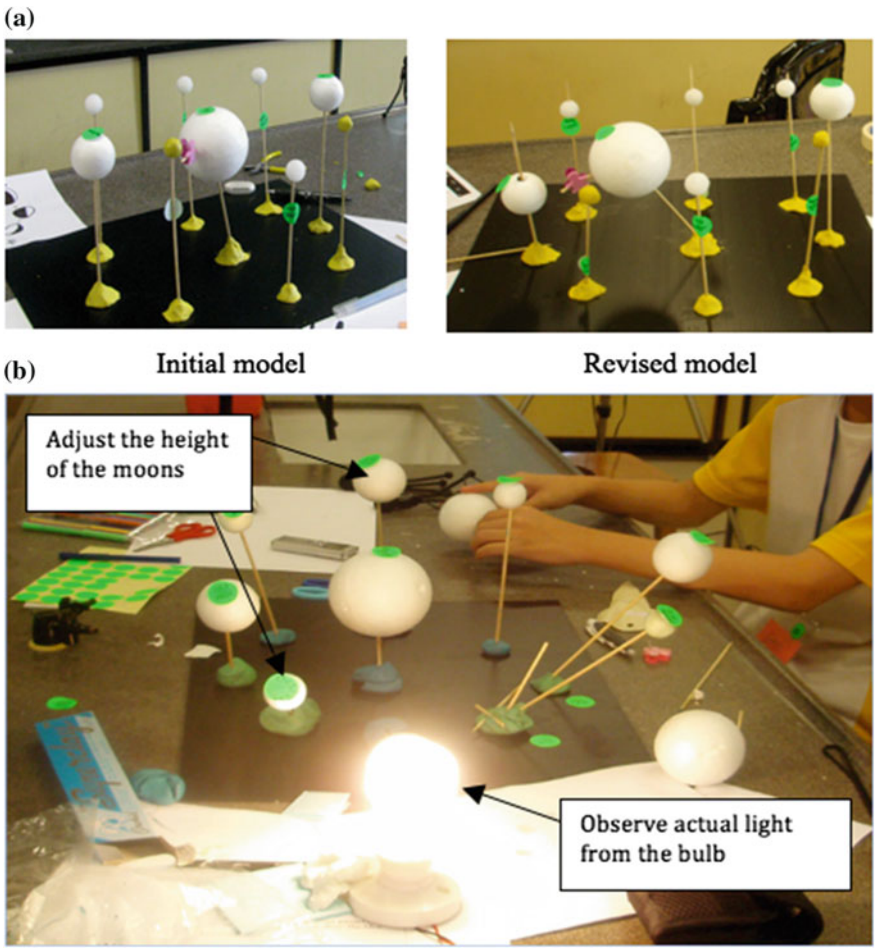


Fig. 10.6 a, b 3D model modified by students

engage in remodeling activities. As shown in Fig. 10.6a, initially all moon phases were arranged in a flat horizontal plane, but during the remodeling process (see Fig. 10.6b), the participants started to rearrange the moon phases in order to form the tilted plane of the Moon's orbit so as to prove that the Moon can receive sunlight at the Moon-Earth-Sun arrangement.

Furthermore, HJ used a computer simulation model to show the tilted plane of the Moon's orbit. He mentioned:

> You can see if the moon comes between the Sun and the Earth, you have what we called solar eclipse. That means if you are on the earth, you cannot see the sun because it is blocked by the moon. But before the moon blocks the sun, you can still see a little bit of the moon. So (we) can see the moon. You see? So in that particular sense, Jane's comment was correct. (We) Can see the moon. …. During the lunar eclipse? Look at this diagram. Now

> the earth is blocking the moon. So cannot see the moon what. Okay. So all these your good friend says about your model is correct. So two of you ah, are correct during the lunar eclipse and solar eclipse.

Hence, by using the model of the Moon's tilted orbit, he showed how to use the model to predict important relevant phenomena such as the solar eclipse and lunar eclipse. HJ also explained why he argued that Jane's argumentation could be reasonable during the solar eclipse at the position of Sun-Moon-Earth whereas Alice's argumentation could be also correct during the lunar eclipse at the position of Sun-Earth-Moon.

Discussion

Based on results from the aforementioned four EMMA workshops in informal learning settings, the following section will consider four emerging design principles, which can guide subsequent EMMA workshops toward developing a participatory learning environment: Developing observation-based inquiry, Constructing multimodal modeling, Generating argumentations using models, and Remodeling through evaluation and reflection.

- **Developing observation-based inquiry**: Observation-based inquiry encourages participants to reflect on their everyday experiences and to explore inquiry. This inquiry can be collaboratively generated by participants, experts, or researchers based on their sky observations with naked eyes or/and telescopes including pictures and videos taken by others. Specifically, in astronomy education, observation, whether it was made in the authentic environment (Sherrod & Wilhelm, 2009; Trundle, Atwood, Christopher, & Sackes, 2010) or designed virtual environment (Bakas & Mikropoulos, 2003), provides learners with embodied experiences in an authentic learning environment. This does not only facilitate learners' conceptual learning, but also enhances their motivation and interests. In EMMA workshops, the research team provided participants observation experiences both in field trips and through observation photos. In the EMMA Workshop IV, students were even encouraged to observe the night sky using their own telescopes. In some workshops where real observation was hard to achieve, we used observation photos or simulation software to engage the participants. Learners usually got excited about authentic observation and became more engaged. However, observation should serve the purpose of more than just triggering students' interests, and it should also meaningfully relate to the content they are going to learn.
- **Constructing multimodal modeling:** Astronomy is by nature a very interdisciplinary science. By stressing the sociocultural context of science literacy, this practice-inspired design also takes an interdisciplinary approach to experience, understand and explore diverse interpretations of astronomical phenomena from different perspectives across subject areas. This interdisciplinary approach aims

to have participants apply new knowledge across a variety of contexts for deep understanding. For instance, our EMMA workshops show that there are five main modes of meaning-making: (1) Sky observations, (2) 2D drawing, (3) 3D physical modeling with clay/Styrofoam, (4) 3D computer modeling, and (5) ICT-integrated storytelling. Physical models have a true 3D perspective at a system level (e.g., solar system, Sun-Earth-Moon system) so that they may be viewed from or moved to different spatial locations. Participants used their 2D drawing and hands to demonstrate the planets' movements or illuminations. This mode of meaning-making gave participants an opportunity to further explore their ideas about planetary light and motion in addition to working with 3D computer models. Computer modeling includes creating and manipulating 3D objects, running and observing the model from multiple levels and perspectives within the 3D space, and visualizing and collecting data of the system's process with provided symbolic representations. EMMA Workshop III showed that ICT-integrated storytelling offered participants opportunities to make an aesthetic response to astronomical phenomena. Specifically, ICT-integrated storytelling aimed to support emotional and cognitive challenges; thereby, motivating participants to reflect on their experiences of astronomical phenomena and communicate what they experienced with others.
- **Generating argumentations using models**: Our participants throughout the EMMA workshops were encouraged to make argumentations and to use their models in order to communicate with others. This involved communicating and socially negotiating with others through on-line and off-line. In particular, as described in the finding, the real sky observation triggered them to ask all kinds of questions. Most of the questions could not be answered on the spot, but the research team encouraged them to record the questions and argumentations for later exploration through multimodal modeling tools. In the process, participants applied their knowledge and learned skills and theories through problem solving. This accords with the notion of situated cognition put forward by Brown, Collins, and Duguid (1989) where knowledge is viewed as "situated, being in part a product of the activity, context and culture in which it is developed and used" (p. 32). Throughout the EMMA workshops, the main facilitator HJ gradually developed the strategy of argumentation. For instance, as indicated in EMMA IV, rather than telling the fact, HJ attempted to challenge his students with alternative ideas while encouraging them to construct models to find out evidences to support and explain their own argumentations.
- **Remodeling through evaluation and reflection**: Generating such argumentations is also an iterative practice because EMMA workshop participants constantly need to evaluate and modify their models as they deeply explore the system's processes exploiting various affordances. Such reflective engagement helps them make connections among their own observations, observation-based inquiry, and conceptual understanding.

These emerging design principles imply the importance of teachers' informal learning opportunities that in turn will support their students' informal learning.

In particular, our research suggests the value of the partnership between researchers and teachers. For instance, our research team collaborated with the teacher for more than 5 years through co-designing workshops. We discovered that he had changed in his pedagogy, such as asking for argumentation more frequently in his questions. He has initiated an Astronomy Club in his school and highlighted the importance of modeling as a way of learning in his lesson designs. He also adopted the learning-through-teaching approach to train senior students to be prospective facilitators of the junior students. Teachers need to participate in such a community of learners that can facilitate their role change from delivering information to designers and meaning-makers by collaborating with their students, researchers and other stakeholders.

Acknowledgements The project described in this chapter was supported by the Office of Education Research, National Institute of Education, Singapore. I thank all the participants and researchers in this project. As indicated in the article, some of the data from this chapter was previously presented at some conferences including three manuscripts submitted to Journal of Science Education and Technology, International Journal of Science Education, and Journal of the Learning Sciences.

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