Research and Practice in Technology Enhanced Learning
Vol. 8, No. 3 (2013) 363－384

COMPUTER-ENHANCED MULTIMODAL MODELING FOR SUPPORTING A LEARNER GENERATED TOPIC

MI SONG KIM†

Faculty of Education, University of Western Ontario, 1137 Western Road,
London, ON, Canada N6G 1G7
misong.kim@uwo.ca
https://www.edu.uwo.ca

WEI CHING LEE

Nanyang Technological University, 1 Nanyang Walk,
Singapore 637616, Singapore
weiching.lee@nie.edu.sg

This study describes the emergence of a multimodality modeling workshop involving a 3D computer model, aiming to facilitate the workshop participants' learning of their self-generated astronomy topic – lunar libration. This qualitative study took place in designing learning environments in informal learning contexts that leveraged five university students' interests and prior knowledge in astronomy, observation experiences and emerging questions. The findings show that the modified visual representation in a computer model improved the quality of their observation experiences and assisted them to consolidate their understanding of lunar libration. Further, computer-enhanced multimodality mediated by modeling software (i.e. Astronomicon) promoted not only learners' self-directed exploration but also collaborative discussion toward understanding of the lunar libration. We consider implications for promoting learner-generated topics supported by computer-enhanced multimodal modeling.

Keywords: Computer-enhanced multimodal modeling; a learner-generated topic; lunar libration; informal learning; embodied modeling mediated activity; embodied cognition.

1. Introduction

We have worked with an experienced physics teacher in Singapore to co-design Embodied Modeling Mediated Activity (EMMA) workshops, to promote astronomy teaching and learning with an emphasis on multimodality and embodied cognition. By adopting design-based research, we have also focused on designing a participatory learning environment that can support learner-generated topics in informal settings outside classrooms. As the result of collaborative efforts working with learners (i.e. EMMA workshop participants) including practitioners (i.e. physics professors) and teachers, we argue that multimodal modeling activities allow learners to develop a deep understanding of astronomical phenomena (Kim, 2011; Kim, Lee, & Ye, 2012, 2012a; Kim, Lee, Ye, & Kim, 2012). Learning astronomy through sky observation and multimodal modeling activities defined as design principles motivated students to reflect on their prior knowledge or funds of knowledge (Kim, Lee, & Kim, 2011; Kim, Lee, & Ye, 2012a). Specifically, a modeling approach supports learners' diverse ways of reasoning in their own unique ways by allowing multiple representations, such as diagrammatical, pictorial, kinesthetic and propositional, rather than focusing on modeling mainly from an expert's viewpoint. Drawing upon such findings with respect to the affordances of multimodal modeling activities, we continue to explore the affordances of 3D computer models in learning astronomical phenomena in informal learning contexts.

Compared with formal learning contexts, informal learning tends to have more flexibility; learners are viewed as agents of designing learning activities rather than as passive recipients of information transferred from more knowledgeable others (e.g. teachers, facilitators) (Boyer & Roth, 2006; Kim, 2011; Kim & Lee, 2013). Bevan and his colleagues (2010) noted that informal learning promotes authenticity by emphasizing both learning tools and learning contexts pertaining to learners' interests and strengths (Bevan et al., 2010). Further, astronomy is not a school subject in Singapore, so it is essential to explore informal learning contexts not only to meet workshop participants' interests, experiences, knowledge, needs, and challenges, but also to empower them by promoting their collaborative experience, which leads to their development of a sense of ownership and empowerment. In that sense, this article is part of a larger study that examines how to develop a participatory learning environment in informal learning (Kim & Kim, 2011-2013). In particular, we designed multimodal modeling activities involving 3D computer modeling so that learners use the best available learning tools to generate, share, reflect and evaluate their multimedia-rich inquiries (Hansen, Barnett, MaKinster, & Keating, 2004; Keating, Barnett, Barab, & Hay, 2002). Through close collaboration with school teachers, university professors and workshop participants, we have adopted an interventionist approach, designing informal multimodal modeling workshops with multiple iterations of design, implementation, evaluation, and re-design. Rising above these objectives, in this paper we seek to investigate what could be affordances and changes of computer-enhanced multimodal modeling to support a learner-generated topic (i.e. lunar libration) within an informal learning context. Specifically we aim to answer two research questions: 1) How can multimodal modeling be integrated to support learning of a learner-generated topic?; and 2) What are the challenges of learning lunar libration through multimodal modeling?

2. Theoretical Framework

2.1. *Learner generated topics in technology-enhanced participatory learning environments*

It is common for scientists in scientific research practice to engage in an iterative process of generating inquiry questions, building their own models to model the targeted phenomena, and using and evaluating the models to explore the relationships between variables within the system. Many science educators have adopted inquiry-based pedagogy for modeling-integrated teaching and learning (Kenyon, Schwarz, Hug, & Baek, 2008; White & Frederiksen, 1998). In recent years, there has been a great emphasis on the importance of digital technologies for having learners engage in collaborative construction of knowledge within a participatory learning environment (PLE). Barab et al. (2001) defined PLEs as systems that "engage students in the construction of products requiring practices that embody complex concepts, necessitate collaboration, and contextualize learning with contexts in which problem solving and inquiry are fundamental aspects of the learning process" (p. 48). This approach to PLE also emphasizes that learning involves learners' developing understanding through collaborative construction of sharable artifacts to support complex learning within technology-enhanced learning environments. However, PLEs have mostly focused on supporting topics generated either by curriculum designers or teachers/workshop facilitators. Little attention has been given to learner-generated topics, although recently some studies (Biddulph, Symington, & Osbourne, 1986) call for special attention to be paid to student-generated questions that are viewed as psychological tools for advancing learners' understanding of science in formal learning (Kim, 2011; Kim, Lee, Ye, & Kim, 2012; Chin, 2002). Therefore, in our study, we aim to establish PLEs that encourage learners to construct both personally meaningful multimodal models and practically functional representations, in order to enhance shared understanding and collaboration with others.

We paid special attention to learner-generated topics (i.e. lunar libration) that could motivate and allow learners, including teachers or facilitators, to co-construct knowledge and build a community of learners working with practitioners or experts through observing, communicating and reflecting on their prior knowledge, experiences, interests, beliefs, perceptions and questions. With an emphasis on multimodal modeling, as well as 2D drawing and 3D physical models, we integrated a 3D computer modeling tool (called Astronomicon, Cybernet-System, 2004) to enhance a meaningful learning experience for making connections between observable phenomena and targeted concepts. Similar to other free Astronomy software (e.g. Stellarium, Celestia), Astronomicon also allows users to create and manipulate 3D celestial objects. That is, Astronomicon lets users not only visualize 3D celestial objects with symbolic representations (e.g. orbital planes) but also view celestial objects from multiple perspectives, which is widely recognized as critical to astronomy learning (Barnett, Yamagata-Lynch, Keating, Barab, & Hay, 2005; Parker & Heywood, 1998). Compared with other software, the Astronomicon could afford the opportunity for users to create their own celestial objects by setting up properties of planetary bodies. Thus, Astronomicon was intended to motivate the workshop participants to test their hypotheses by perceiving, evaluating, and predicting the impact of certain parameters of planetary bodies on astronomy phenomena (i.e. lunar libration) (see Table 1). For all of these theoretical reasons, we were interested in how Astronomicon could enhance collaborative learning and deeper learning beyond simple simulation and representation. Also, we hoped to assist learners in developing a scientific understanding of lunar libration through participation in the EMMA workshops, in which our workshop participants were able to create and use visual thinking tools or visual argumentation tools to develop a deeper understanding of lunar libration.

2.2. *Lunar libration and technology-enhanced multimodal modeling*

Lunar libration is not one of the big ideas covered in astronomy education that research by Lelliott and Rollnick (2009) reviewed over a 35-year period, from 1974 until 2008. Drawing upon their own observations of the sky using a telescope that made it possible to observe the phenomenon of lunar libration, our workshop participants became interested in exploring lunar libration. What is lunar libration? The Moon has synchronous rotation, so the same side of the Moon always faces the Earth. In other words, only 50% of the Moon is visible from the Earth because the Moon rotates about its axis at the same rate that the Moon orbits the Earth. However, because of the complicated motions of the Moon, we can see a little bit around the east and west limb and over the north and south poles, allowing up to 59% of the Moon's surface to be viewed from the Earth (Vandenbohede, 2005). This extra 9% is called the libration zones because the gentle wobbling motion of the Moon in the Earth's sky is called libration. Vandenbohede (2005) also noted "observing and even the basic task of identifying formations in the libration zones is not easy." In an effort to address this learner-generated topic, we needed to find a way for teachers or facilitators to help the workshop participants better understand fundamental concepts pertaining to lunar libration.

Modeling is the process of representing abstract ideas or coordinating the structures of a system by simplifying, quantifying and representing with the purpose of explaining, predicting and communicating with others how the ideas work (Kim, 2011; Kim & Ye, 2013; Kim, Lee, & Ye, 2012a; Shen & Confrey, 2007). Models can be classified into two types: internal models and expressed models (Gobert & Buckley, 2000). Internal or mental models refer to individuals' internal representation of the explanatory mechanisms that underlie particular phenomena, whereas expressed models can be thought of as the external representations of internal models. Expressed models can be diagrammatic (e.g. drawing of causes of seasons), physical representations with concrete materials (e.g. a globe), or computational models (e.g. 3D simulations). Compared to traditional print-based instructional methods, constructivist approaches to science teaching and learning have recognized the importance of multimodality in learners' development of conceptual understanding (Hull & Nelson, 2005; Lemke, 2004; Roth & Lawless, 2002). Especially in the domain of astronomy, multiple sensory modalities like visual, verbal, tactile, imagery, and kinesthesia are triggered when learners are engaged in multimodal modeling activities. With respect to learners' challenges about motion and perspective as the two core concepts in astronomy, several studies have shed light on the affordances of 3D computational modeling (e.g. simulating motions and multiple perspectives of celestial objects) in providing a versatile platform for learners to experience, explore, research, communicate and expand spatially related astronomical abstract concepts (Barnett et al., 2005; Baxter & Preece, 1999; Keating et al., 2002; Hansen et al., 2004).

Only relatively recently has interest surged in the interactive aspects of multimodal modeling, with an emphasis on the role of perceptual and motor systems in developing cognitive processes in terms of embodied cognition (Lakoff & Johnson, 1980). For instance, Shen and Confrey's (2010) research on teachers' enactment of kinesthetic-based instruction argues for making connections between observable phenomena and targeted concepts, beyond simply demonstrating the actual motion of the celestial objects. Drawing upon Latour's (1990, 1993) notion of transformation in science, Shen and Confrey's (2007) study also shows a variety of positive effects of comparing and contrasting diverse models, which in turn led to the development of "transformative modeling" through recognizing limitations of existing models, resolving inconsistency between models, stabilizing constructs of the model, and communicating ideas with others. Along these lines, they also encouraged learners to construct their own models rather than confining themselves to using existing models. After constructing their own models, Shen and Confrey (2010) recommend that opportunities should be provided for learners to communicate and share their models with others.

3. The Study

Based on embodied cognition and multimodality, we co-designed EMMA workshops for bridging sky-gazing practices and understanding planetary motion/light through collaboration with teachers, practitioners, and the workshop participants (Kim, Lee, & Kim, 2011; Kim, Lee, & Ye, 2012). Within EMMA, each mode of modeling (e.g. 2D drawing models, 3D physical models, 3D computer models) engages learners in in-depth inquiry processes addressing their prior knowledge, beliefs and experiences, followed by modeling exploration and discussion to enhance understanding. The curriculum design was situated in informal learning settings. The research team used design-based research (DBR) (Barab & Squire, 2004; Collins, 1992), so that we went through iterative cycles of co-designing, implementing, and refining EMMA learning activities (see Table 1) with teachers/facilitators, practitioners and the workshop participants in order to improve both their learning and modeling tools (e.g. the computer software). New content was added based on learner-generated topics, and modeling materials and tools were further refined to meet the needs of learners. Three astronomy phenomena were focused in the workshop: lunar libration, Venus transit and lunar eclipse. All topics were authentic and significant events based upon their sky observation experiences in their university observatory. In this paper, we report only the learning of lunar libration because that topic was generated by the participants, and also involved more 3D computer modeling compared to the other topics.

By employing a DBR research methodology, this qualitative research focused on an understanding of how participants constructed and appropriated multimodal models (e.g. 2D drawings, 3D physical models, 3D computer models) for better understanding of lunar libration, rather than investigating possible cause-and-effect relationships. It was impossible to confirm and predict learning or outcomes because individual participants as active agents were continuously changing themselves through interaction with the environment (i.e. Embodied Modeling Mediated Activity). In other words, learning (or outcome) emerged out of the internal mechanisms of the participants from their internal dynamics that were construed from their own lived experiences situated in particular socio-cultural contexts (Kim, 2014, in press). As such, the three EMMA workshops were tools and outcomes of design simultaneously. Hence, in this study, there was no predetermined and confirmed learning attached to learning environments. Instead, learning depended on the participants' knowledge and prior experiences.

3.1. *Participants and EMMA workshops*

There were five male students majoring in physics: HQ, KH, RY, CX, and KY. We will refer to them with pseudonyms. They had strong interests in Astronomy and were enrolled voluntarily in a university's research project that required them to manage an observatory and conduct research related to telescope installation and image processing. According to their advisor, they were dedicated and diligent students with strong physics knowledge. Their advisor also was our collaborator in our research project who had been teaching physics and astronomy for undergraduate and graduate students. The modeling activities employed in this study also were co-designed with one experienced physics teacher who had taught physics more than 10 years at college and high schools.

The EMMA workshops listed in Table 1 had been co-designed as previously mentioned. We conducted a pre-workshop meeting to understand learners' background and learning interests. The research team introduced the concepts of modeling, modeling artifacts and computer modeling tools (i.e. Astronomicon, Stellarium). Learners were interested not only in the topics of lunar eclipse and Venus transit for further study following the guidance of the research team, but also in the topic of lunar libration on their own initiative. All these topics were closely related to their observatory project in which the Moon was one of the celestial objects they had observed frequently. These topics required researchers to refine learning activities and materials to accommodate learners' interests, knowledge and experiences. Learners spent approximately eight hours during two EMMA workshops to explore lunar libration, lunar eclipse and Venus transit. Multiple modeling materials were prepared such as Styrofoam balls, paper plates, globes, wooden sticks, etc. In order to build a participatory learning environment, the workshops called for special attention to learners' prior knowledge, including learner-generated questions and models. They also decided on modeling tools to construct multimodal models (e.g. virtual computer model, 2D sketching, 3D concrete model) during their discussion and exploration of the topics. After discussion, learners shared their understanding with respect to their models. Following two modeling workshops, Workshop III offered them with opportunities to design their own lesson plan for a workshop.

Table1. The procedure of EMMA workshops and data collection.

Phase and its Duration	Main Activities	Data Collection
Pre workshop meeting (3 hours)	• Learners shared their interests, perceptions about science, learning and modeling. • Learners discussed and decided topics that they chose to study further. • Researchers introduced concepts of modeling, modeling artifacts and computer modeling tools (i.e. Astronomicon, Stellarium).	• Video clips • Pre-surveys • Pre-concept test (Venus transit)
Workshop I: Lunar libration and lunar eclipse (4 hours)	• Learners generated their own inquiry regarding lunar libration and lunar eclipse. • Learners created and explored multimodal models (i.e. 2 D drawings and Astronomicon) to understand and investigate the phenomena of lunar libration and lunar eclipse. • Learners presented their understanding based on their models. • Facilitators provided feedback. • Learners reflected on their learning.	• Video clips • Camtasia © video (screen capture of learners' interaction with Astronomicon) • Pre-concept maps of lunar libration • Artifacts: group concept maps, mathematical models • Writing reflection on learning using a notebook computer
Workshop II: Venus transit (4 hours)	• Learners explored and investigated Venus transit through modeling. • Learners presented their understanding. • Facilitators provided feedback. • Learners reflected on their learning and assessed their own learning progress.	• Video clips • Questions about Venus transit • Post-concept maps of Venus transit and lunar libration • Writing reflection on learning using a notebook computer
Workshop III: (4 hours)	• Learners shared their perceptions concerning good teaching and learning practice. • Learners discussed learning objectives and related learning activities with respect to Venus transit to prepare for their own workshop for teaching secondary students the topic of Venus transit.	• Video clips • Lesson plan

3.2. *Data collection and analysis*

We collected various data source materials, including learners' pre/post-concept maps of lunar libration, video-taped modeling activities, their reflections, artifacts, and surveys (see Table 1). We employed pre-concept maps to understand learners' prior knowledge and their initial inquiries about lunar libration. Artifacts such as group-generated concept maps and mathematical models were captured as photos to investigate their learning progression and outcomes. We collected post-concept maps and reflection notes to evaluate their learning outcomes at the end of the workshops. Data analysis was heavily based on video data. The interactions between learners and Astronomicon were recorded using Camtesia©, in videos that recorded every action learners made on computer screens as well as related verbal discussion. Thus, Camtesia videos informed researchers about learners' decision making and their learning procession. Besides Camtesia videos, video recorders were also set up in the front and the back of the classroom in order to record learners' presentations and group discussion. These videos revealed interactions among them during the modeling activities.

The data analysis emerged inductively through interactions with data source materials in three steps. First, researchers revisited all the videos and selected six relevant videos based on contents that were closely related to the learning of lunar libration. The videos were categorized based on the nature of activities, such as concept map construction, interaction with Astronomicon (i.e. Camtesia videos), and presentations. Our findings were heavily based on the concept map construction videos and Camtesia videos, while the presentation videos were employed to triangulate the findings about their learning progression. Secondly, episodes were defined in each video according to content-oriented and activity-oriented issues. Examples of content-oriented issues are the definition of lunar libration, the Moon's elliptical orbit, and eccentricity, whereas the examples of activity-oriented issues are: using models to illustrate the motions of the Moon, observing the Moon with preset values, and exploring different viewpoints. Thirdly, in order to investigate how learners co-constructed models, we modified the methods of constructing networks of action-relevant episodes (Barab, Hay, & Yamagata-Lynch, 2001) with an aim to trace the "distributedness" of the models using concept map construction videos and Cametesia videos. Each episode was coded with the dimensions of issues, initiators, resources and practices. For instance, using concept map construction videos, a new visual illustration was labeled as a resource when it was generated. Subsequently, when it was referred or used in the following episodes, it was coded as a resource. As indicated in Figure 2, a pictorial path represents the ways models were generated and how learners used them later in their discussion. The Camtesia videos were also coded in a similar manner while addressing specific features of Astronomicon such as changeable parameters, changeable visual representations, changeable viewpoints, default information, and process simulation.

4. Findings

4.1. *Constructing and using multimodal models by collaborative efforts*

With respect to lunar libration, learners' initial inquiry was "what is the exact mechanism for libration?" We encouraged them to create concept maps of lunar libration individually to hypothesize causes of lunar libration, followed by a group activity where they co-constructed a concept map to share and negotiate their own concept maps and further discussed possible strategies to support their hypotheses. Figure 1 indicated the sequences of their discussion. First, HQ defined the meaning of lunar libration with written text (see D1 in Figure 1), and then he drew the Moon's elliptical orbit (see D2 in Figure 1) in order to explain the Moon's rotation and revolution. Relying on his 2D drawing and gestures, HQ attempted to explain that when the Moon is at the apogee node (see point A in D2 in Figure 1) it moves relatively slower so that we see more surface area of the Moon. As such, at the perigee node (see P in D2 in Figure 1), the Moon moves relatively faster in an elliptical orbit of the Moon.

The concept map had been improved through their collaborative efforts among learners. For instance, after listening to HQ's explanation, KY added an arrow between "factor 1" and "why" to explain how the elliptical orbit of the Moon causes lunar libration (see the written text in D2 in Figure 1). However, KH and RY were not convinced by HQ's argumentation of how the elliptical orbit could attribute to the lunar libration. Hence, CX constructed and used a 2D drawing (see the shaded part in D3 in Figure 1) to explain the extra visible surface area of the Moon, which was the libration zone. Through such engaging and sustained communication, mediated by multimodal models, they collaboratively searched for resources and effective strategies to prove the abstract theory of lunar libration, for instance, "first way to prove: check if the angular

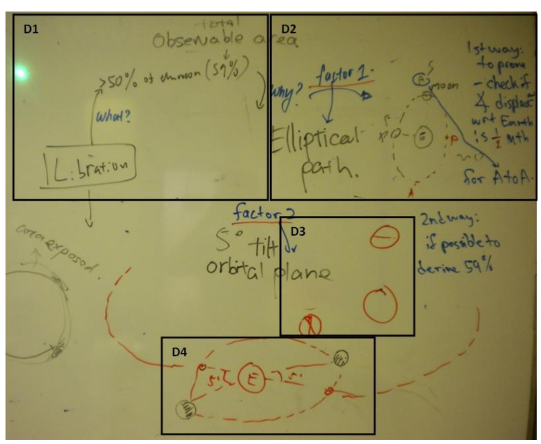


Figure 1. The sequences of the development of collective concept map.

displacement with refers to the Earth is ½ month from A to A." This also allowed them to fulfill their authentic need to observe the angular displacement when the Moon revolves from apogee (A) to apogee (A).

While discussing how the Moon's tilted orbital plane could attribute to lunar libration (called latitude libration), they created a new 2D diagram (see D4 in Figure 1) to illustrate and explain the extra visible surface area of the upper part of the north pole and the lower part of the south pole of the Moon. As Figure 2 indicated, these findings show that each new diagram (i.e. D1, D2, D3, D4 in Figure 1) was co-constructed by collaborative efforts among learners to argue, explain, reflect, clarify and improve learners' hypotheses, and these drawings as models also were reused, evaluated and revised frequently in subsequent conversations. For instance, D2 was created by HQ in episode 2 for arguing and explaining the elliptical orbit of the Moon around the Earth, and then it was again used by HQ for further expanding into other topics such as eccentricity, why we only saw one side of the Moon, and how we observed lunar libration when the Moon was at apogee and perigee. Other group members also referred to D2 in order to ask questions in the following episodes along their discussion. When their discussion shifted to a new topic, they created a new model to support communication. Figure 2 showed how CX created D4 to argue the effect of the 5-degree tilt of the plane of the Moon's orbit around the Earth to the plane of the ecliptic, which was used later to discuss how the orbital plane inclination exposed more of the upper or lower part of the Moon. Further, such diverse representations allowed learners to compare and contrast models toward the integration of two causes of the lunar libration.

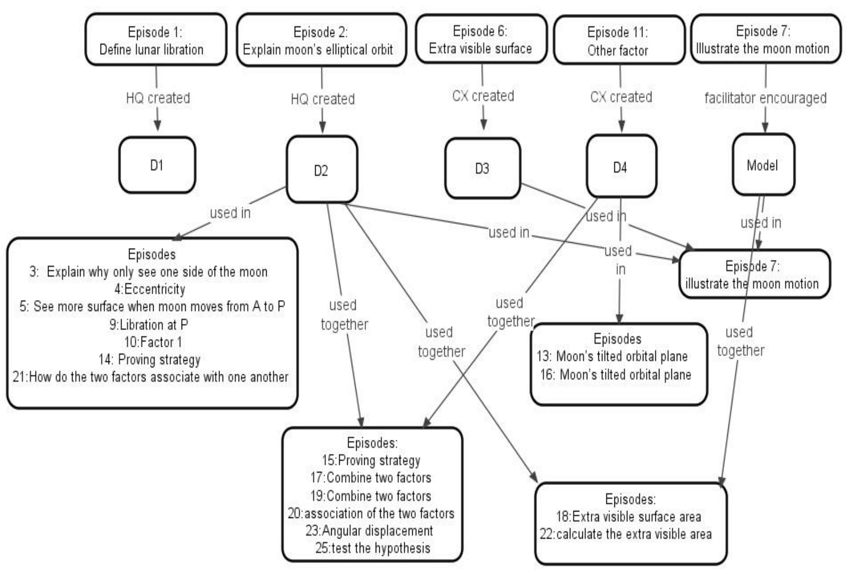


Figure 2. The concept map of constructing and using 2D drawing models in episodes.

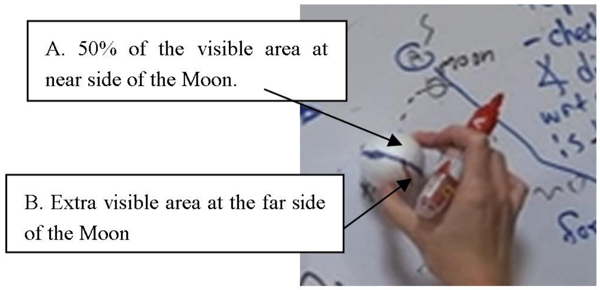


Figure 3. 3D physical model of the libration zone.

In addition to such 2D drawings, facilitators encouraged learners to construct 3D physical models in their communication and collaboration (in episode 7, see Figure 2). Following their 2D drawing in D2 (see Figure 1), they attempted to draw a horizontal line on the Styrofoam ball (representing the Moon) to represent the 50 % of the visible area (see A in Figure 3) and then CX added another line to demonstrate and explain the libration zone at the far side of the Moon (see B in Figure 3). They continuously used their own 3D physical model together with their 2D drawings and gestures for arguing the Moon's motion and exploring the extra visible area of the Moon. In other words, learners collaboratively used diverse multimodal models such as a learner-constructed 3D physical model, gestures of the Moon's rotation and revolution, and their 2D drawings of factors causing the lunar libration for exploring, visualizing and explaining the extra visible moon surface area (called the libration zone) drawing upon their own arguments.

Hence, there was a dialectical relationship between multimodal modeling activities and learners' collaborative efforts. In other words, multimodal modeling activities motivated learners to engage in their dynamic interaction with others emotionally, socially and cognitively through actively sharing, communicating, negotiating and appropriating their prior knowledge (e.g. physical and mathematical understanding) and multimodal models (e.g. 2D drawings, 3D physical models, verbal and written descriptions, gestures, concept maps). These collaborative efforts also allowed learners to construct, use, evaluate and revise multimodal modeling activities to argue, prove and understand that the Moon's elliptical orbit and tilted orbital plane were the two factors that caused the lunar libration.

4.2. *Integrating concrete models with abstract theories using computer modeling*

After consolidating their understanding of the abstract theory of lunar libration as described earlier, the research team further attempted to challenge learners to construct and use 3D computer models toward the development of deeper understanding of lunar libration. Specifically, the research team asked learners to prove and explain the abstract theory by providing concrete evidence such as measuring the angular displacement caused by the two factors leading to the total visible Moon's surface area as 59%: (a) the Moon's elliptical orbit, and (b) the titled orbital plane. As the following excerpt indicated, initially they perceived the task of "proving the theory" (turn 2) the research team suggested as "easy" (turns 6, 7) because they mainly attempted to simulate (see turns 3, 4) the astronomical phenomenon, that is the lunar libration. They simply assumed that Astronomicon would have allowed them to simulate the various positions and motion of the Moon around the Earth if they had found how far is the Earth from the Moon (see turn 8) that in turn could have visualized the north and south poles of the Moon to represent the libration zone easily. CX's utterance ("the plane tilted", see turn 8) also revealed learners' prior knowledge of the Moon's axis being slightly inclined relative to the Earth's axis. Hence, learners had their own perceptions of computer technology use that showed up in their utterances that they made available to each other. That is, Astronomicon would easily allow them to visualize their own 2D drawings of the two factors that cause the Moon's libration (see D2 and D4 in Figure 1). However, through thinking aloud concerning how to measure the angular displacement of the Moon initiated by HQ (turn 9), learners collaboratively made sense of abstract concepts (i.e. perigee, rotation) and became aware of a modeling task as requiring their effortful, purposeful and active engagement with a focus on emerging shared objectives such as finding out the possible ways of modeling the rate of rotation (see turns 9-15).

Turn 1	CX: See, the theory says 59%.
Turn 2	KH: Then, how to prove the theory?
Turn 3	HQ: Using… Don't know how. This, this. This one needs simulation. Simulation.
Turn 4	CX: This needs simulation.
Turn 5	[CX points to D4 on the whiteboard, see Figure 1]
Turn 6	CX: This easier.
Turn 7	HQ: Ya, this is easy.
Turn 8	CX: Then you just find the distance away then you can roughly see from the plane tilted, then.
Turn 9	HQ: This one [HQ points to D2, see Figure 1] you need to gauge. Like, here you see more [pointing to Perigee in D2] because of the rate of change.
Turn 10	KY: Ya.
Turn 11	HQ: So maybe this one is harder to prove.
Turn 12	KH: So we need to find out the, the rotation?
Turn 13	KY: The rate of rotation.
Turn 14	KH: Rotation.
Turn 15	HQ: This one rotates. It's how now, you want to model it.

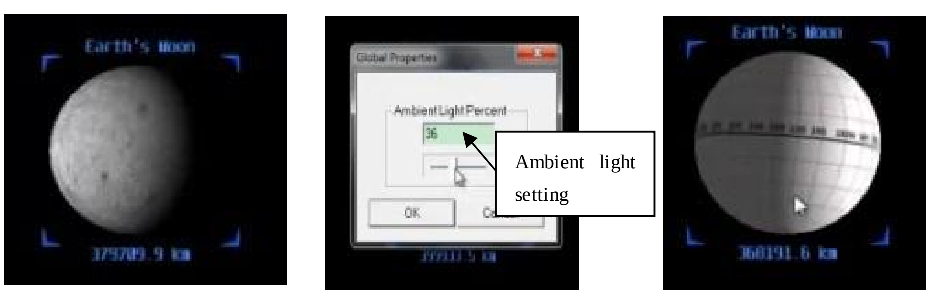
The research team requested learners to work in groups with a focus on group transactions for investigating libration in the context of using Astronomicon. They formed groups voluntarily. There were two groups in investigating the lunar libration using Astronomicon: group A with two members (CX and KY) and group B with three members (HQ, KH and RY). It was not difficult for them to learn the software, so they

(a) Default moon image (b) Imposed graphic of "moon-with-grid"

Figure 4. Modified visual representation of the Moon.

easily constructed a virtual system consisting of the Sun, the Earth and the Moon, and figured out ways of understanding Astronomicon's default settings and observing the celestial objects from different viewpoints (e.g. observing the Moon from the center of the Earth, observing the Moon above the Earth). Following a realization of the importance of observation to learning astronomy defined based upon previous EMMA workshops (Kim, Lee, & Ye, 2012a), the research team attempted to explore the role of computer modeling in providing learners with a collaborative learning context in which they were encouraged not only to involve observation but also to test their hypotheses concerning the factors of lunar libration such as the impact of eccentricity and inclination on the libration zone. Unlike their expectation as indicated in turns 1-15, it was not easy for them to experience the libration zones by running the default setting of the Moon surface image (see Figure 4a) within Astronomicon. This limitation of Astronomicon in turn encouraged the research team to design a visual representation of a "moon-with-grid" graphic (see Figure 4b).

Also, the research team employed an ambient light setting to enable learners to observe the whole moon (see Figure 5). The revised concrete moon image (Figure 5C) afforded them to experience the abstract theory of lunar libration in a more concrete, authentic way.



(a) Initial view (b) The ambient light setting (c) Improved view

Figure 5. The ambient light setting in Astronomicon.

4.3. *Using and revising computer models for explaining and predicting lunar libration*

Initially, Group A observed the Moon's libration without changing any of the parameters in Astronomicon. When they became familiar with the software (i.e. Astronomicon), they started to manipulate the Moon's parameters in order to test their hypotheses and prove them. The excerpt below illustrated Group A's initial attempt to investigate these parameters.

Turn 16	[Astronomicon simulates the motions of the Moon in which the wobble to a small degree occurs.]
Turn 17	KY: No, 我是在想说 (What I was thinking is), 你 (you) remove 掉 (away) Earth 的 ('s), it ah, 那个 (the) eccentricity. Then 你(you) remove 掉(away) …
Turn 18	CX: Moon's eccentricity. Eccentricity, then 你 (you) remove.
Turn 19	KY: Oh, er. Moon, moon, moon. Moon's eccentricity and Earth's, eh, moon's inclination. Then you see what's the …
Turn 20	CX: Moon's tilt.
Turn 21	KY: Ah. Then you see what happens.
Turn 22	CX: Is it, is it 50 or 20, 30%
Turn 23	KY: Ah. [Clicking "Insert/Edit", then "edit selected object". The body option box appears (see Figure 6).]
Turn 24	KY: Oh.
Turn 25	CX: It is moon, ok.
Turn 26	KY: This eccentricity.
Turn 27	CX: 下面 (bottom portion).
Turn 28	KY: Oh, 等一下 (hold on for a moment), er ... Eccentricity.
Turn 29	CX: Eccentricity. 0.0548.
Turn 30	KY: 0 point
Turn 31	CX: 0548.
Turn 32	[Value of eccentricity is changed to "0"]
Turn 33	KY: 它的 (it's) inclination?
Turn 34	CX: Inclination, 5.1454.
Turn 35	KY: 5 point
Turn 36	CX: 1454.
Turn 37	[Inclination is changed to "0"]
Turn 38	KY: Ya, which is correct, 50%.
Turn 39	CX: It's 50% ah.
Turn 40	KY: Em, it (always) not moving ... Correct right?
Turn 41	[The moon appears static in Astronomicon.]

Figure 6 showed a window consisting of all changeable parameters including eccentricity, inclination, and the Moon's axis tilt when learners interacted with the "edit body" option in Astronomicon. They decided to set the Moon's eccentricity, plane's inclination and the Moon's axis tilt to zero (see turns 23-37).

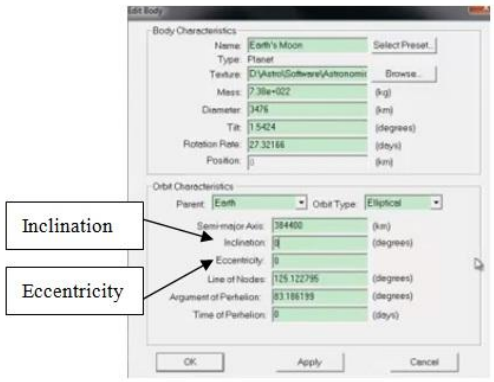
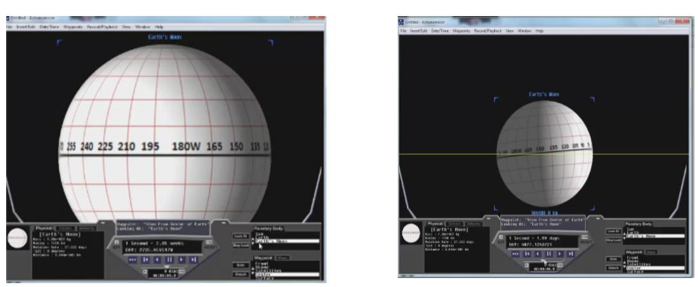


Figure 6. Changeable parameters in “Edit body” option in Astronomicon.

This transaction with Astronomicon allowed them to experience that the Moon became static without wobbling (see Figure 7a, turns 38-41). This concrete observation using a computer tool confirmed their hypotheses that eccentricity and inclination attributed to the lunar libration. When the eccentricity and inclination were set to zero, the Moon stopped wobbling. As a result, the Moon appeared static all the time, and in turn only 50% of the Moon’s surface was visible (see Figure 7a).

Following their observation of no lunar libration using Astronomicon, CX and KY reset the plane inclination as “5.1454” degree and the eccentricity as “0” (turn 42). They ran Astronomicon at the speed of 1 second that was equal to 1.99 days (turn 45). This allowed them to observe, explain and predict how the Moon could move up and down vertically (turns 46-52). They also actively negotiated and consolidated how to estimate the angular displacement caused by the plane inclination (called latitude libration) (see



a) Static moon (b) Moon with vertical displacement

Figure 7. Vertical angular displacement.

turns 55-69). That is, KY estimated the displacement by dividing one grid (representing 15 degrees) by 3 (turn 60) whereas CX did by 5 (turn 59). In order to resolve this discrepancy, they reused the computer model several times to prove and confirm the maximum angular displacement (turns 63-70). Eventually, they agreed on 10 degrees as the maximum angular displacement (see turns 71-73).

Turn 42	[CX types “5.1454” in the inclination parameter and “0” in the eccentricity parameter and clicks the “Apply” and “Ok” keys.]
Turn 43	CX: Ok. Ah. Ok. Then.
Turn 44	KY: Then, 你就 (you just) run.
Turn 45	[Timer tells that the speed is “1 second=1.99 days”.]
Turn 46	KY: Actually it goes down.
Turn 47	CX: So it goes down.
Turn 48	KY: Basically I think this point really moves up and down. You see.
Turn 49	CX: Huh?
Turn 50	KY: Let’s see here.
Turn 51	CX: Why not we take the maximum? We take the maximum, then, we take maximum. Then we know the moon displacement, right?
Turn 52	KY: Ok.
Turn 53	CX: Then 我们就这样 (we will do this). Then 我们 (we) find the angular displacement.
Turn 54	KY: Yes, ok.
Turn 55	CX: Oh, each grid is 15 degrees.
Turn 56	KY: So like that is roughly ...
Turn 57	CX: 5?
Turn 58	KY: A fifth?
Turn 59	CX: 5.
Turn 60	KY: 3 degree. 3 degree
Turn 61	CX: One, there, like that is 15 degree [pointing at one unit of grid], so you divide by 3, you see.
Turn 62	KY: vertically what. It’s not dividing by 3 right? Thinking about 5 or 3?
Turn 63	KY: Ya. You move it fast, fast.
Turn 64	[Timer is adjusted to various values]
Turn 65	Is there any (more displacement)? No?
Turn 66	KY: 再来 (Again). There, 你再来，再 (do it again, do it) faster.
Turn 67	KY: 过了没有 (Has it passed?) 5?
Turn 68	CX: 15 degree divided by 3.
Turn 69	KY: By 3?
Turn 70	CX: 5, 5, 10.
Turn 71	KY: 10, then ...
Turn 72	CX: Degree.
Turn 73	KY: Ok, ok. Sorry, sorry. Ok, 10 degree.

The workshop participants used a similar method to obtain the longitudinal angular displacement caused by the eccentricity of the Moon’s orbit around the Earth, which they found on the Internet. To prove this abstract theory, they reset inclination to “0” and

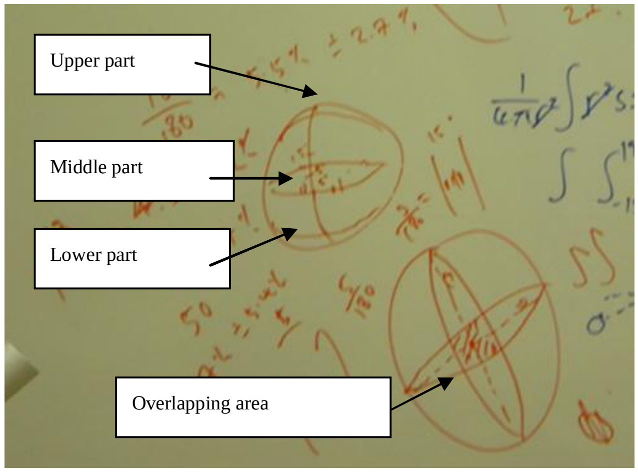


Figure 8. Measuring the angular displacement in Group A.

eccentricity to "0.054", which allowed them to observe the lunar libration zone on its left and right side of the Moon. They also estimated such a longitudinal angular displacement as 13 degrees. Hence, drawing upon these computer-modeling experiences, they eventually elucidated the latitude and longitudinal angular displacement data by using 3D computer models Astronomicon created as concrete evidence to make sense and evolve collaborative understanding of the abstract lunar libration theory of the extra 9% of visible Moon's surface area. Further, they constructed a 2D diagram (see Figure 8) that represented how they were engaged in the percentage calculation of the angular changes through applying their prior knowledge (i.e. mathematics, physics) as their own funds of knowledge. That is, they made an assumption that the vertical displacement in the middle part of the Moon would be equivalent to the displacement in the upper and lower parts of the Moon. This led them to conclude that the maximum latitude displacement was 10 degrees that in turn contributed to 5.5 % of extra visible surface area (10°/180° × 100%) while the maximum longitudinal displacement was 13 degrees contributing to 7.25% of the libration zone (13°/180° × 100%). It turned out that they overestimated the libration zone as 12.75% compared to 9% that they found on the Internet. At result, they also came up with another 2D drawing (see Figure 8) to consolidate that such a difference was caused through double counting in the overlapping area (see Figure 8). They had not solved this limitation due to time constraints.

5. Discussion and Implications

Computer-enhanced multimodal modeling activities situated in an informal learning context effectively mediated the workshop participants' deeper understanding of a learner-generated topic, lunar libration in three ways: (a) constructing and using multimodal models by collaborative efforts; (b) integrating concrete models with abstract theories using computer modeling; and (c) using and revising computer models for explaining and predicting lunar libration. As these findings indicate, understanding the learner-generated topic, lunar libration, required learners to engage in concrete observation experiences of the Moon's movement in relation to its properties (i.e. eccentricity, inclination). A computer modeling tool, Astronomicon, allowed learners to experience the complex motion of the Moon and its visible surface area by creating concrete models to observe, experiment and predict astronomical phenomena. They also had authentic, hands-on experiences concerning the impacts of different parameters on the libration zone through an active manipulation of parameters (see Figures 6 and 7). Further, within this participatory learning environment, researchers were also actively engaged in not only providing useful modeling tools but also revising and co-constructing modeling tools toward enriching learners' embodied experiences such as designing a visual representation of a "moon-with-grid" graphic (see Figure 4b), which in turn afforded learners a greater in-depth observation and understanding. Drawing upon such emerging new design features in Astronomicon, learners also were actively engaged in multimodal modeling activities using Astronomicon where they attempted to collect useful data from concrete models and to apply them into their funds of knowledge (i.e. mathematical models) resulting in measuring the angular displacement (see Figure 8). Further, the interactive features of multimodal modeling activities with learner-defined parameters in a participatory learning environment helped them to explain, prove, understand, and predict the attributive factors and their impacts on lunar libration.

With special attention paid to concrete hands-on experiences of observation and spatial cognition, therefore, we recommend that educators develop such a participatory learning environment in which learning involves learners' developing understanding through collaborative construction of multimodal models toward a deeper understanding of learner-generated topics. As discussed earlier, the interactions among learners were enhanced through participating in multimodal modeling activities that were designed by researchers and practitioners with an aim to offer them meaningful experiences of constructing, using, evaluating, and revising multimodal tools (e.g. gestures, 2D drawing, 3D physical models, 3D computer models, mathematical models) to explore astronomical phenomena. Compared to their formal learning experiences, there was no clear division of labor among the workshop participants (or learners), researchers, and facilitators. Learners became active participants by generating topics they were interested in and getting involved in sharing, constructing, communicating and revising multimodal models in respect to the targeted topic. Their advisor and one physics teacher, as facilitators, used their content-specific expertise to identify core concepts and related observation experiences. Researchers also contributed their expertise of multimodal modeling tools (i.e. Astronomicon) to leveraging their affordances.

Consequently, in a participatory learning environment mediated by computer-enhanced multimodal modeling activities, learners were encouraged to approach emerging problems in multiple ways supported by multimodality, which in turn led to the reconsideration of instructional materials, tools, and pedagogical approaches for teachers/facilitators and researchers. Hence, the learning process was more holistic, inclusive, and interactive not only for the workshop participants but also for all the members including teachers/facilitators and researchers by reflecting on, sharing and valuing their prior experiences, interests, and knowledge. Based on this collaborative practice, we suggest the importance of establishing a sustainable learning community in informal contexts beyond classroom teaching and learning by integrating varied expertise toward learners' deeper understanding of astronomical knowledge related to their generated topics. Also, some efforts will be needed to sustain collaboration between schools and informal learning communities that encourage authenticity, different disciplines and multimodalities in learning contexts (Bevan et al., 2010). Further, multimodal modeling also implies the important role of observation that offers opportunities for learners not only to recognize inconsistencies between an observation experience and models they create but also to promote collective inquiry among them. Specifically, observation, whether is made in the authentic environment (Trundle, Atwood, Christopher, & Sackes, 2010) or designed in virtual environments (Bakas & Mikropoulos, 2003), provides learners with embodied experiences. This not only facilitates learners' conceptual learning but also enhances their motivation and interest (Kucukozer, Korkusuz, Kucukozer, & Yurumezoglu, 2009). Hence, such multimodal modeling calls for a new conceptualization of learning as participating in practice with an emphasis on bodily active engagement and the integration of sensory behavior and cognition, which have not been used very much in formal learning.

Acknowledgments

The project described in this paper was supported by the Office of Education Research, National Institute of Education, Singapore. We thank all the students and teachers including researchers participated in this project.

References

Bakas, C., & Mikropoulos, T. (2003). Design of virtual environments for the comprehension of planetary phenomena based on students' ideas. *International Journal of Science Education*, *25*(8), 949–967.

Barab, S. A., Barnett, M., Yamagata-Lynch, L., Squire, K., & Keating, T. (2002). Using activity theory to understand the systemic tensions characterizing a technology-rich introductory astronomy course. *Mind, Culture & Activity*, *9*(2), 76–107.

Barab, S. A., Hay, K. E., Barnett, M., & Squir, K. (2001). Constructing virtual worlds: Tracing the historical development of learner practices. *Cognition and Instruction*, *19*(1), 47–94.

Barab, S. A., Hay, K. E., & Yamagata-Lynch, L. C. (2001). Constructing networks of action-relevant episodes: An in situ research methodology. *The Journal of the Learning Sciences*, *10* (1 & 2), 63–112.

Barab, S. A., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences*, *13*(1), 1–14.

Barnett, M., Yamagata-Lynch, L., Keating, T., Barab, S. A., & Hay, K. E. (2005). Using virtual reality computer models to support student understanding of astronomical concepts. *Journal of Computers in Mathematics & Science Teaching*, *24*(4), 333–356.

Baxter, J. H., & Preece, P. F. W. (1999). Interactive multimedia and concrete three-dimensional modelling. *Journal of Computer Assisted Learning*, *15*(4), 323–331.

Bevan, B., Dillon, J., Hein, G. E., Macdonald, M., Michalchik, V., Miller, D., Root, D., Rudder, L., Xanthoudaki, M., & Yoon, S. (2010). *Making science matter: Collaborations between informal science organizations and schools. A CAISE inquiry group report*. Washington, DC: Center for Advancement of Informal Science Education (CAISE).

Biddulph, F., Symington, D., & Osborne, R. (1986). The place of children's questions in primary science education. *Research in Science and Technological Education*, *4*(1), 77–88.

Boyer, L., & Roth, W.-M. (2006). Learning and teaching as emergent features of informal settings: An ethnographic study in an environmental action group. *Science Education*, *90*, 1028–1049.

Chin, C. (2002). Student-gnerated questions: Encouraging inquisitive minds in learning science. *Teaching and Learning*, *23*(1), 59–67.

Collins, A. (1992). Towards a design science of education. In E. Scanlon & T. O'shea (Eds.), *New directions in educational technology* (pp. 15–22). Berlin: Springer.

Cybernet-System. (2004). *Astronomicon: Celestial construction tool kit*. Ann Arbor, MI: Cybernet Systems Corp.

Gobert, J. D., & Buckley, B. C. (2000). Introduction to model-based teaching and learning in science education. *International Journal of Science Education*, *22*(9), 891–894.

Hansen, J. A., Barnett, M., MaKinster, J. G., & Keating, T. (2004). The impact of three-dimensional computational modeling on student understanding of astronomical concepts: A quantitative analysis. *International Journal of Science Education*, *26*(11), 1365–1378.

Hull, G. A., & Nelson, M. E. (2005). Locating the semiotic power of multimodality. *Written Communication*, *22*(2), 224–261.

Keating, T., Barnett, M., Barab, S. A., & Hay, K. E. (2002). The virtual solar system project: Developing conceptual understanding of astronomical concepts through building three-dimensional computational models. *Journal of Science Education & Technology*, *11*(3), 261–275.

Kenyon, L., Schwarz, C., Hug, B., & Baek, H. (2008, March). *Incorporating modeling into elementary students' scientific practices*. Paper presented at the annual conference of the National Association for Research in Science Teaching (NARST). Baltimore, MD.

Kim, M. S. (2011, September 5-10). *Embodied modeling-based inquiry activity: Vygotsky revisited*. Paper presented at the International Society for Cultural and Activity Research (ISCAR). Rome, Italy.

Kim, M. S. (2014). Doing social constructivist research means making empathetic and aesthetic connections with participants. *European Early Childhood Educational Research Journal*, *22*(5).

Kim, M. S. (in press). Technology-mediated collaborative learning environments for young CLD children and their families: Vygotsky revisited. *British Journal of Educational Studies*.

Kim, M. S., & Kim, B. (2011-2013). *An embodied modeling-based inquiry activity towards participatory learning environments*. Grant awarded by the Office of Education Research, National Instutute of Education, Singapore.

Kim, M. S., & Lee, W. C. (2013). A case study of understanding the seasons in informal learning. In *Proceedings of the 86th NARST Annual International Conference*. Puerto Rico: NARST.

Kim, M. S., & Ye, X. (2013). Transforming the learning difficulties to teaching moments. In *Proceedings of the 10th International Conference on Computer Supported Collaborative Learning*. Madison, USA: International Society for the Learning Sciences.

Kim, M. S., Lee, W. C., & Kim, B. (2011). Modeling the solar system: A case study of Singaporean youth. In S. Barton et al. (Eds.), In *Proceedings of Global Learn Asia Pacific 2011* (pp. 998–1003). Melbourne, Australia: AACE.

Kim, M. S., Lee, W. C., & Ye, X. (2012, April 13-17). *Teacher's instructional strategies in multimodal modeling-based activities for teaching and learning the moon phases*. Paper presented at the 2012 Annual Meeting of the American Educational Research Association (AERA). Vancouver, BC, Canada.

Kim, M. S., Lee, W. C., & Ye, X. (2012a). Toward leveraging digital storytelling for a participatory learning culture. In *Proceedings of the E-Learning – World Conference on E-Learning in Corporate, Government, Healthcare, & Higher Education* (pp. 1818–1826). Montreal, Canada: AACE.

Kim, M. S., Lee, W. C., Ye, X., & Kim, B. (2012). Enriching multimodality in learning through integrating computer modeling to support a learner generated topic: Lunar libration. In *Proceedings of the 20th International Conference on Computers in Education* (pp. 143–150). Singapore: Asia-Pacific Society for Computers in Education.

Kucukozer, H., Korkusuz, M. E., Kucukozer, H. A., & Yurumezoglu, K. (2009). The effect of 3D computer modeling and observation-based instruction on the conceptual change regarding basic concepts of astronomy in elementary school students. *Astronomy Education Review, 8*(1), 104–118.

Lakoff, G., & Johnson, M. (1980). The metaphorical structure of the human concetual system. *Cognitive Science*, *4*, 195–208.

Latour, B. (1990). *Pandora's hope: Essays on the reality of science studies*. Cambridge, MA: Harvard University Press.

Latour, B. (1993). *We have never been modern*. Cambridge, MA: Harvard University Press.

Lelliott, A., & Rollnick, M. (2009). Big ideas: A review of astronomy education research 1974-2008. *International Journal of Science Education*, 1–29.

Lemke, J. (2004). The literacies of science. In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 33–47). Arlington, VA: International Reading Association and National Science Teachers Association.

Parker, J., & Heywood, D. (1998). The earth and beyond: Developing primary teachers' understanding of basic astronomical events. *International Journal of Science Education*, *20*(5), 503–520.

Roth, W. M., & Lawless, D. (2002). Science, cultures and the emergence of language. *Science Education*, *86*, 368–385.

Shen, J., & Confrey, J. (2007). From conceptual change to transformative modeling: A case study of an elementary teacher in learning astronomy. *Science Education*, *91*(6), 948–966.

Shen, J., & Confrey, J. (2010). Justifying alternative models in learning astronomy: A study of K-8 teachers' understanding of frames of reference. *International Journal of Science Education*, *32*(1), 1–29.

Trundle, K. C., Atwood, R. K., Christopher, J. E., & Sackes, M. (2010). The effect of guided inquiry-based instruction on middle school students' understanding of lunar concepts. *Research in Science Education*, *40*(3), 451–478.

Vandenbohede, A. (2005). *Observing the lunar libration zones*. Retrieved from http://users.telenet.be/lunar/jpeg/libratieboek.pdf

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition & Instruction*, *16*(1), 3.