Development of a Multi-Viewpoint AR-Based Mobile Learning System for Supporting Lunar Observation

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***Abstract*—Observation of lunar phase in the real world is an important part of lunar phase learning. In this research, mobile Augmented Reality (AR) technology was used to develop a multi-viewpoint AR-based mobile learning (M-VARML) system for moon observation that can be used in the real world environment. An experiment was conducted to evaluate the usefulness of our system. Ten participants were given five moon observation tasks, which they had to perform manually and using the M-VARML system. After each task, they were given follow-up questionnaires on the usefulness of the functions in the system. Finally, they were asked about the operational usability and the effect our system had in motivating them to pursue lunar observation. The results show that the M-VARML system is effective in improving the observation and learning of students and in enhancing their motivation to pursue lunar learning.**

***Keywords*-Mobile Augmented Reality; Lunar Observation; Smart phone; Lunar Phase;**

I. Introduction

Lunar phases are astronomical phenomena existing in daily life. Still, they may be one of the most difficult concepts to teach in astronomical education [1]. Research has been conducted to study the development and usefulness of educational materials for lunar phase learning using several different approaches. One type is the virtual learning environment. For example, a learning system is available that allows the user to manipulate astronomical models of the sun, earth, and moon which exist as visible, tangible bodies [2]. The tangible learning system, titled "The Phase of the Moon", was implemented in a six-grade elementary school science class unit. A 3D animation moon phase concept system has been applied to science learning in the fourth grade [3]. Several issues, however, arise with a virtual learning environment. For example, much of the research is confined to restricted locations such as classrooms or laboratory. Lack of outdoor learning seriously limits students from clearly understanding the position and movement of moon phases in the real sky. This does not encourage people to observe the moon in their daily lives. A virtual learning system is abstract and difficult to apply to the real world environment. For example, after students obtained elevation angle of the moon information from a virtual learning system, it was difficult for them to measure the actual elevation angle of moon in the real world [4].

One way to circumvent these issues is to introduce observation-based learning (OBL) in lunar phase teaching. Planetarium curators believe that the most important element in astronomy education is observing real stars outdoors [5]. Suzuki confirmed that on-going observation and conversation could enhance college students' ability to understand the phases of the moon [6]. An activity that could greatly aid a student in lunar phase learning is observing the moon in the real world environment. Through observations, a student can understand the rising and setting of the moon. Further, by daily observation of lunar phases, they can comprehend the periodic waxing and waning of the moon and understand the relationship among the sun, earth, and moon. An approach to OBL in lunar education includes using an application on mobile device. A lunar observation support system that can be used with mobile phones was developed [7]. This system enables students to observe the moon in open air and send observational data through their mobile phones to the server. However, this system had issues in the real world environment. Observation of the moon is often restricted by time, place, and weather. On cloudy or rainy days, the observer failed to see the moon. Furthermore, in cities, it is often inconvenient for observers to view the lunar phases due to high rises or light pollution. Learners could not find time on thirty days to completely observe a lunar

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cycle because of their busy schedules. One typical solution is to use Augmented Reality (AR) technology to address these issues. Augmented Reality (AR) is a variation of Virtual Reality (VR); it adds virtual information to the real world and interacts with it. Kikuo and Tomotsugu [8] consider AR as a new pattern that could be applied in teaching that has great potential for future development. This new and unique teaching method and strategy can help learners with little computing experience to interact easily. Interest in mobile AR applications has grown with the dramatic increase in the usage of smart phones in the past few years. Present day smart phones and tablets integrate fast processors with graphics hardware, large touch screens, and onboard sensors (camera, GPS, compass, and accelerometers) to create gadgets that are ideal for indoor as well as outdoor AR experiences, such as, CityViewAR [9].

There are a number of popular AR astronomy applications, such as Google Sky Map, Star Walk, and Stellarium Mobile. These applications utilize the smartphones GPS and sensors to locate the stars. These applications name the star that is being viewed through the phone. The purpose of these applications is astronomy observation. However, they are not designed for teaching; for example, they have not dynamic latitude and longitude line to help students to study the azimuth and elevation angle of moon in the sky. In addition, there are no functions that show one-month moon orbit, shape, and age in the AR view. Most application AR views do not have a camera view, and thus a visual view in the real world environment cannot be obtained. Further, these applications do not provide a function that explains the mechanism of lunar phases, as it relates to everyday observation of lunar phases.

Setozakai [10] proposed that it is necessary to help students to understand the astronomy topics from multi-viewpoints, namely the geocentric model and the heliocentric model viewpoint. It states that it is important to switch between the two viewpoints to understand astronomy subjects. Based on Setozakais theory, Kawasaki [11] indicated that it is important to observe the appearance of moon from the earth viewpoint, and, at the same time, to understand the relationship between the sun, earth, and moon from the viewpoint with sun as the center of the universe to study the mechanism of lunar phases. Therefore, it is optimal to construct a multi-viewpoint observation environment for students to observe lunar phase in the real world environment.

In this research, mobile AR technology was applied to develop a multi-viewpoint AR-based mobile learning system for supporting moon observation that can be used anytime and anywhere, irrespective of the weather conditions. In order to assess the learning effect, usability and motivational effect of this system, a task-based experiment was conducted. Ten participants were given five moon observation tasks to perform manually and using M-VARML system. After each task, they were given follow-up questionnaire about the usefulness of the functions in the system. Finally, they were asked about the operational usability and the learning attitude of system. The results show that the M-VARML system enhances a learner's learning ability for lunar observation. It has high motivational effect on lunar observation and operational usability.

II. Research Method

This section explains the learning goal of the system, the system design, the system interface, and its functionality.

A. Learning Goal of Lunar Observation

The proposed system was developed as an educational tool for lunar phase observation. The learning functions of the system are based on learning indicators in the student's science course unit, titled "Lunar Phase". This course set the learning goals of moon observation of M-VARML as follows:

(1) Observe the moon, its azimuth and elevation angle in the sky every day.

(2) Observe the moon every day to witness it rising in the east and setting in the west.

(3) Observe the moon every day to understand the periodic waxing and waning of moon in 30 days.

(4) Observe the azimuth and altitude, changing of the shape of the moon by observing the moon at the same time and location for 30 days.

(5) Understand the positional relationship among the sun, moon, and observer.

(6) Understand the positional relationship among the sun, earth, and moon from the viewpoint with sun as the center of the universe.

(7) Understand the relationship between moon age and shape of lunar phases.

B. System Outline

The M-VARML System allows learners to observe the appearance of moon from the earth viewpoint, at the same time, understand the relationship of sun, earth and moon from the sun-center of universe viewpoint to study the mechanism of lunar phase. The outline of system is as shown in the Fig.1. The learners could switch the two viewpoints to observe moon and achieve the learning goal of moon that we have stated.

The M-VARML system has two main views: the AR view and the Universe View. In order to achieve the learning goals of lunar phase observation (see Section II-A), we set the following specifications of the learning environment in M-VARML system:

(a) The azimuth, elevation angle, shape, moon age of moon can be observed in the real sky through the AR view function.

(b) The azimuth, altitude of sun can be observed in the real sky through the AR view function.

(c) The orbit of moon between 1:00 AM and 12:00 PM can be observed in the real sky using the "One Day" function.

(d) The periodic waxing and waning of the moon in the sky can be observed through the "SetDay" function.

(e) The relationship between moon age and the shape of moon can be observed through the "SetDay" function.

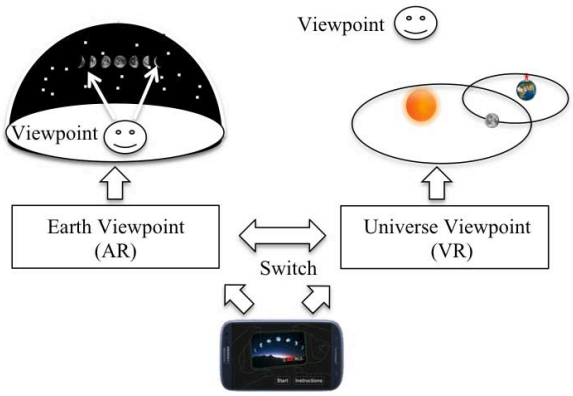


Figure 1. Outline of the M-VARML system.

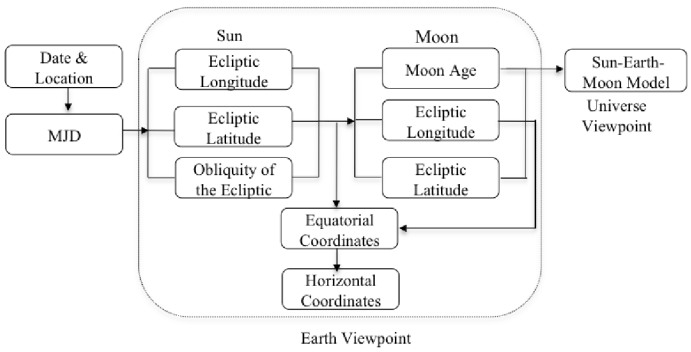


Figure 2. Astronomy Simulation Model.

(f) The positional relationship among the sun, observer, and moon can be understood through the AR view.

(g) The relationship among the sun, earth, and moon with respect to the universe can be understood through the universe view function.

In the above specifications, the specification (a) helps to achieve the learning goal (1). The specification(c) helps to achieve the learning goal (2). The specification (d) helps to achieve the learning goal (3) and (4). The specification (e) helps to achieve the learning goal (7). The specification (b) and (f) help to achieve the learning goal (5). The specification (g) helps to achieve the learning goal (6).

C. Astronomy Simulation Model

The M-VARML system is based on the astronomy model that the earth revolves around the sun, and moon revolves around the earth while rotating on its own axis. Our research group has been focusing on the astronomy phenomenon simulation for a long time. In this research, we employ an astronomy simulation model, which is as shown in Fig.2, to develop the M-VARML system for supporting moon observation from multi-viewpoints.

D. AR View Function

The M-VARML system shows virtual moon images overlaid on a live video camera background, making the virtual moon image appear in the real world. To visualize

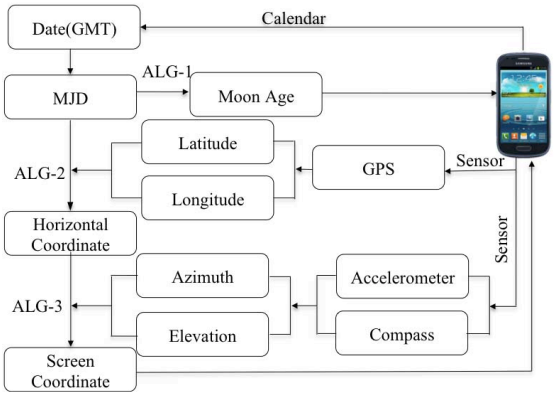


Figure 3. Procedure for Calculating Moon Position in AR View.

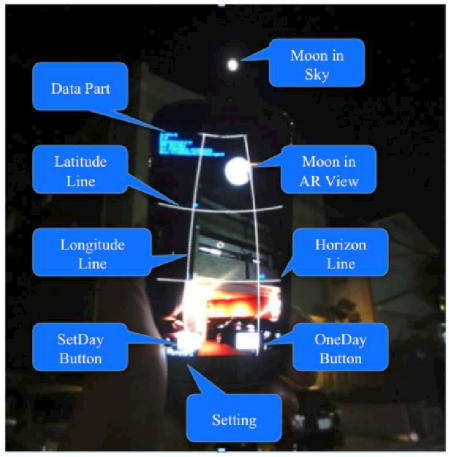
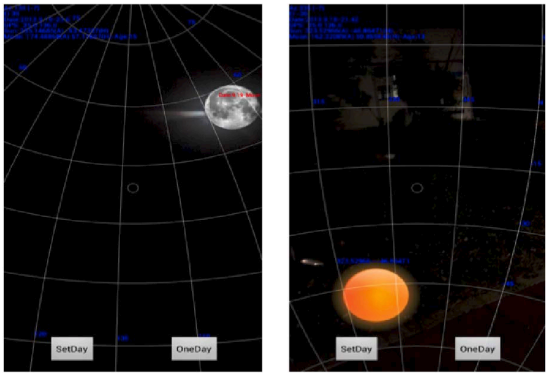


Figure 4. AR View Interface.

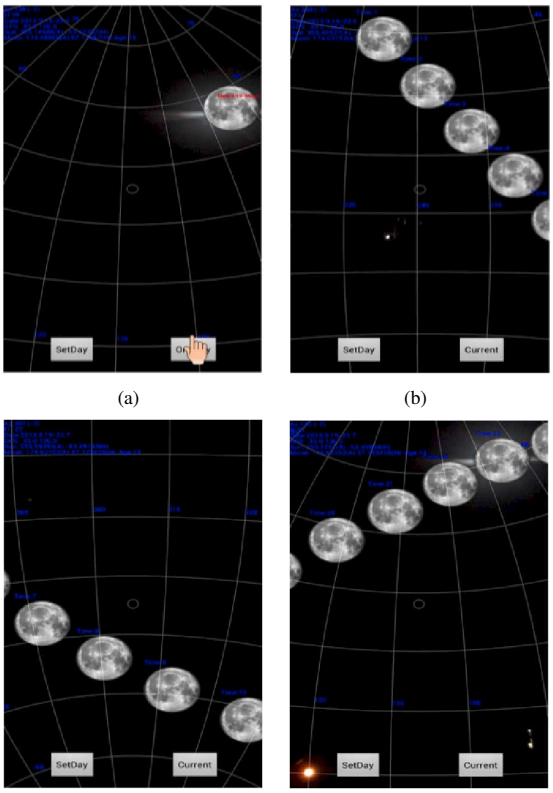
the moon correctly in the AR view, it is necessary to get real-time data from the Smartphone through built-in sensors. This is then combined with the astronomy simulation model (see Fig.2) to calculate the screen coordinates of the visual moon in AR view correctly registered to the real sky, which users observe in the sky.

The procedure for calculating the position of the moon is showed in Fig.3. Firstly, it is necessary to obtain real-time date and time from the calendar of the Smartphone and to calculate the Modified Julian Day (MJD) [12] based on the acquired date and time. Then the longitude and latitude data is obtained using GPS sensor, which is responsible for tracking the geographical position of the Smartphone. Combining these data with the horizontal coordinate algorithm (ALG-2), the moon age, azimuth, elevation of the real-time moon and sun can be computed. The azimuth and elevation data is the horizontal coordinate data of the moon in the sky. This is then used to derive the data of the screen coordinate of the moon and register the moon in the AR view, corresponding to the actual moon in the sky. The accelerometer sensor and compass sensor are used to measure the viewing direction and elevation angle of the Smartphone device that the user is using to observe



(a) Moon (b) Sun

Figure 5. Observe the Real-Time Moon and Sun in AR View.



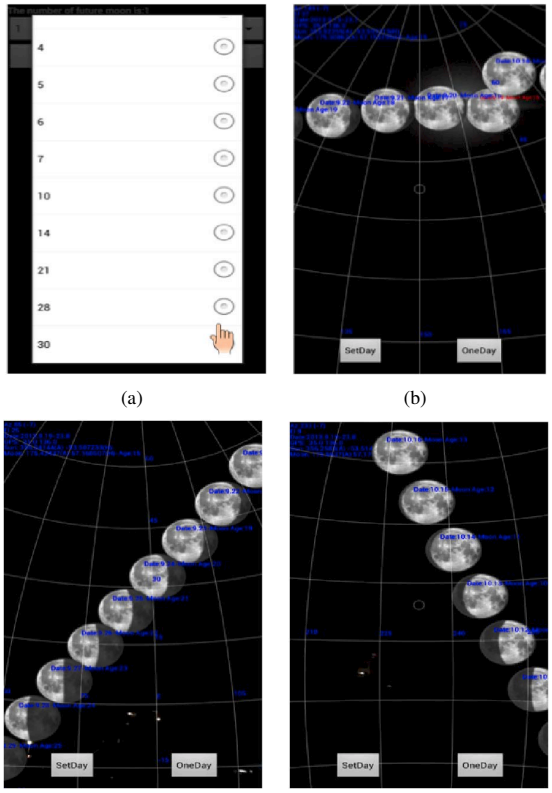
(a) (b)

(c) (d)

Figure 6. Observe One-Day Moon Orbit in AR View.

the moon in the sky. Based on this tracking information, we use the screen projection algorithm (ALG-3) to convert the horizontal coordinates to a screen coordinates to locate the moon in the AR view. After this procedure, the virtual moon is shown in the AR view appropriately maps the moon from the real sky.

The complete AR view interface of M-VARML is shown in Fig.4. The main visual components overlaid in the AR view include the data part, visual moon image, latitude line, longitude line, horizon line, and two buttons. The data part shows the data of orientation, elevation



(a) (b)

(c) (d)

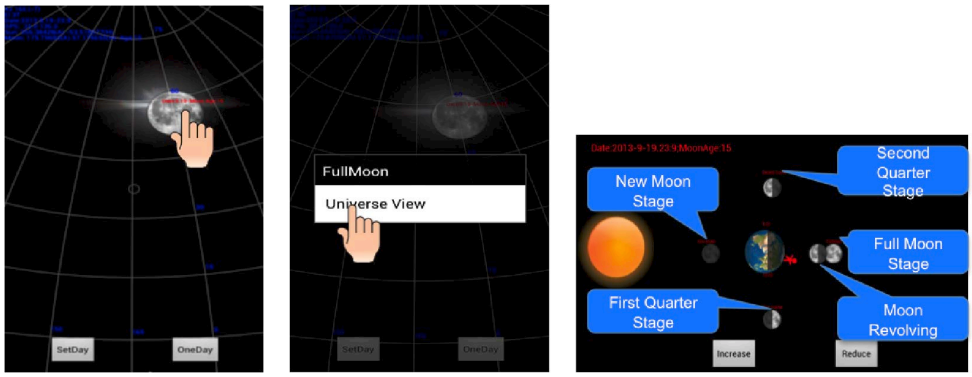
Figure 7. Observe Waxing and Waning of Moon in AR View.

angle of mobile device, GPS, date, time, azimuth (sun and moon), elevation (sun and moon), and moon age. The horizontal line is the zero degree on the latitude line, indicating the horizon in the real world. N, E, S, W indicates the direction that the Smartphone device is pointing to in real world, corresponding to the north, east, south and west directions, which, on combining with latitude and longitude line helps learners search and observe the moon and sun as shown in Fig.5.

The “OneDay” and “SetDay” functions in the AR view meet the specification-learning environment ((c), (d), (e)) as we have set, and the interface as shown in Fig.6 and Fig.7. Through the AR view function, learners not only could construct a visual feeling for lunar observation in the sky, but also could complete the learning goal of lunar observation from earth viewpoint at anywhere, anytime irrespective of the weather restriction.

E. Universe View Function

Learners observing the phases of the moon often wonder what causes this moon phase. The best way to understand the phases of the moon is to examine an earth-moon-sun view. We used the sun-earth-moon orbit astronomy model to develop the Universe view function. In this system, we developed the Universe view function in 2D view space. When the user touches the current moon image in the AR view, the user can see an item named Mechanism. On



(a) (b) (c)

Figure 8. Step into Universe View.

(a) Operating Increase Button

(b) Operating Reduce Button

Figure 9. Interactive Interface of Universe View.

selecting this item, the user steps into the Universe view interface as showed in Fig8.

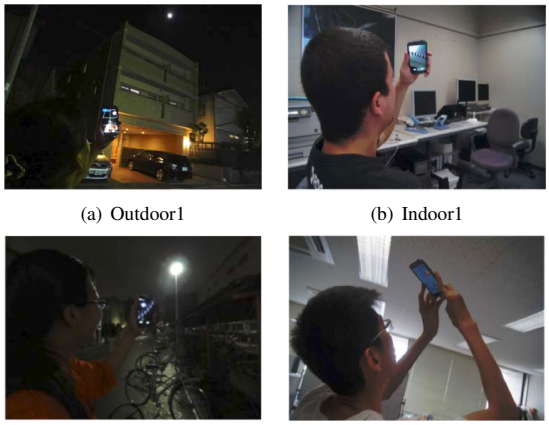
The lunar phases are due to how the sun illuminates the moon and the relative positioning of the earth, moon and sun. Fig.8 shows that the moon revolves around the earth while the earth is rotating on it axis to give us day and night. The person icon on the earth indicates a user standing on the earth observing the moon. It takes the moon about 30 days to revolve around the earth. During those 30 days, as the moon orbits the earth, it grows in size from a new moon, to first quarter, to full moon. It then decreases in size in reverse order to last quarter and then backs to the new moon. Thus, in the Universe View, we visualize four key moon phases of the moon orbit.

As shown in Fig.8(c), when users observe the actual moon in the sky, if they know that the moon age is 15 that particular day, and they see the proportion of the visible moon from the earth viewpoint, they can identify the relationship among the sun, earth, and moon through the Universe view function. Users discern that the moon is at the full moon stage. In the AR view function, users can observe the moon at the same location and time in 30 days. We have also provided users with an interactive function to see the relationship among the sun, earth, and moon at the same location and time during 30 days in the Universe view. Learners can use the increase (see Fig.9(a)) and reduce buttons (see Fig.9(b))to experience it.

The Universe view meets the stated specification of the learning environment (g). The Universe view function is helpful for users to understand the relationship among the sun, earth, and moon while they are observing the actual moon. This improves their knowledge regarding the mechanism of lunar phases.

III. System Implementation

The M-VARML system is developed on the Google Android operating system and software development kit. The developing code toolset is Eclipse, ADT, and Android



(a) Outdoor1 (b) Indoor1

(c) Outdoor2 (d) Indoor2

Figure 10. Experimental situations.

2.1 SDK. The programming language is Java. The application is supported by a range of smart phones and tablet devices that run on Android 2.1 or higher, and have the required sensors (i.e., camera, GPS, electronic compass, and accelerometer). Our M-VARML was implemented on an Android Smart phone. The mobile device was a Samsung Galaxy S3.

IV. Experiment Design

In order to confirm the usefulness and usability of the M-VARML system, a task-based experiment was conducted on ten participants. The ten participants were undergraduate or graduate students with majors unrelated to astronomy. It was verified that they had interest in lunar phase observation. These participants were asked to perform a series of moon observation tasks at different times of day at various locations and under varied weather conditions. Some examples that were selected are shown in Fig.11 including indoor (Fig.10(b) and Fig.10(d)), outdoor (Fig.10(a)), and a cloudy day (Fig.10(c)).

There were a total of five tasks to complete, which were based on the aforementioned learning goals of lunar phase observation (see Section II-A). The tasks are listed in Table I. After each task was completed, the participant was given follow-up questions seeking the usefulness of the M-VARML system corresponding to the task. These questions can be found in Table II. The purpose of these five tasks is to evaluate the usefulness of our system. Fig.11 shows the relationship between the task and the question. The chief purpose of each task was to evaluate the usefulness of each function of the system. Consider task 2 as an example; this task was to evaluate the usefulness of the "OneDay" function, which helps learners to achieve the learning goal (2).

After completing all the five tasks and the corresponding questions about the usefulness, participants were give three questions and a free-response item on usability and attitude of the system. These questions can be found in Table III. All surveys used a five-point Likert-scale, the responses to which were coded as 1 = strongly disagree through 5 = strongly agree.

Table I
Experimental Tasks List

No. Items	Content
Task1	Firstly, participants use the M-VARML system to search and observe real time moon to understand its azimuth and elevation angle without the latitude and longitude line in the AR view. Then users choose the function that shows latitude and longitude line in AR view. Lastly, the participants use the system again to search the moon and observe the azimuth and elevation angle of real time moon in the sky.
Task2	Initially, the participants guess the one-day moon orbit and use their fingers to draw the line of one day moon orbit in the sky. In order to confirm their drawings, they use the "OneDay" function to observe the one day moon orbit in the AR view.
Task3	Firstly, the users guess the one-week moon orbit, the shape and age of the moon. Then, they use their fingers to draw the line of one-week moon orbit in the sky and draw the shape of after one week moon on paper with a pen. In order to confirm their drawing, they use the "SetDay" function and choose seven days moon phase to observe the future one-week moon orbit, shape, and age in the AR view. Then the users guess thirty days of the moons orbit and its shape, and then they use their fingers to draw the line of 30 days moon orbit. Finally, they choose 30 days lunar phase to observe the 30 days moon orbit, shape, and age in the AR view.
Task4	Firstly, the participants guess the position of sun in the sky by observing the shape of the moon. They manually show the positional relationship among the sun, observer, and moon. In order to confirm the positional relationship, users use the system to search the sun and moon in the AR view.
Task5	Initially, the participants guess the relationship among the sun, earth, and moon in the universe view and draw the relationship of these objects on paper with a pen, in accordance with the shape of the moon. Then, they click the moon image to step into the Universe view to verify the relationship among the sun, earth, and moon. Then, they can click on the increase and reduce buttons to explore the relationship between the sun-earth-moon in one month.

V. Experiment Result

A. Usefulness of Functionality

The results of the survey pertaining to the usefulness of system during the task stage are as shown in Table IV. The mean of the questionnaire item Q1 was 4.60, showing that the users deemed the latitude and longitude line in AR view was helpful to them in observing the azimuth and elevation angle of the moon and sun in sky. During task 1, users agreed that the latitude and longitude line is helpful to them in constructing a visual feeling on azimuth and elevation angle in real sky. Therefore, for the usefulness of "OneDay" moon function (Q2), the participants confirmed that this function is very useful in observing the moon rise and set in a day since only one participant was able to draw

Table II
QUESTIONNAIRE ABOUT USEFULNESS OF SYSTEM

No. Items	Content
Q1	The function of latitude and longitude line in system is more helpful to me in understanding the azimuth and elevation angle of real time moon in the starry sky.
Q2	The function of "OneDay" in system is helpful to me in observing the movement orbit of one-day moon in the starry sky.
Q3	The function of "SetDay" in system is helpful to me in observing the periodic waxing and waning of moon in 30 days.
Q4	The function of "SetDay" in system is helpful to me in understanding the relationship between moon age and shape of moon.
Q5	The function of AR view in system is helpful to me in understanding the positional relationship among sun-observer-moon in the real-world environment.
Q6	The function of Universe view in system is helpful to me in understanding the positional relationship among sun, earth, and moon from the universe viewpoint.

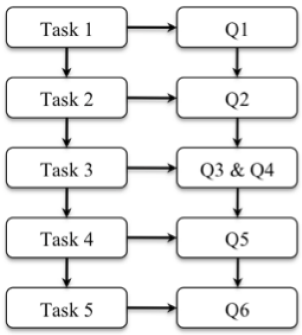


Figure 11. The relationship of the Task and Questions about Usefulness..

Table III
QUESTIONNAIRE ABOUT USABILITY AND THE ATTITUDE OF THE SYSTEM

No. Items	Content
Q7	It is easy for me to operate the system.
Q8	It is interesting for me to use the system to observe lunar phase.
Q9	The system is helpful to me in enhancing my motivation on moon observation.

the correct orbit line of one-day moon in the sky while performing task 2. Similarly, only one user could complete task 3. Some participants even lacked any remote perception of the relationship between the moon age and its shape in the sky. Therefore, the participants conclusively agreed that the function of "SetDay" was helpful to them in observing the periodic waxing and waning of moon,

Table IV
RESULTS OF THE QUESTIONNAIRE ABOUT USEFULNESS

No. Items	1	2	3	4	5	Mean
Q1	0	0	0	4	6	4.60
Q2	0	0	1	2	7	4.60
Q3	0	0	1	2	7	4.60
Q4	0	0	1	4	5	4.40
Q5	0	1	0	5	4	4.20
Q6	1	2	1	2	4	3.60

and in understanding the relationship between the moon age and the shape of the moon. The mean of for Q3 and Q4 was 4.60 and 4.40, proving the same. After completing task 4, most of the participants thought that the AR view was helpful in understanding the relationship between the sun, observer, and moon from the earth viewpoint, as is evident from the mean of 4.20 suggests for Q5. As all the questionnaire items (Q1, Q2, Q3, Q4, Q5) regarding the usefulness of the AR view, have a mean above 4.2, it indicates that the AR view is very helpful to the learners in observing the lunar phase and is able to provide a visual learning experience in the real world. In addition, four participants succeeded in completing task 5; users thought that the Universe view function was helpful in understanding the relationship among the sun, earth, and moon from the universe viewpoint. However, as compared to the aforementioned AR view function, the mean of Q6 was just 3.60 since most of participants considered that it was better to use the 3D space to show the relationship of sun, earth, and moon. Some of participants suggested that it would be better for new users if additional explanatory text were added in the Universe view to aid them in understanding the mechanism of lunar phases. From this analysis and the experimental results, we can draw the conclusion that the functions of our system are very useful for learners for lunar observation.

B. Usability of System

In term of interface designing, most of the users agreed that the system was easy to operate, with the mean of Q7 being 3.80, which is shown in Table V. They were able to operate the system to complete the moon observation tasks. The participants did report that the data in the AR view was a little hard to understand due to the usage of professional terms in that view. According to the interviews, it was reported that the size of the text should be larger or that a different set of colors would make the interface easier to understand.

C. Learning Attitude of System

In addition, the participants appeared to be highly interested in using the system to observe lunar phase, with the mean of Q8 being 4.10. Participants agreed that the system is helpful to them in enhancing their motivation

Table V
RESULT OF THE QUESTIONNAIRE ABOUT USABILITY AND LEARNING ATTITUDE

No. Items	1	2	3	4	5	Mean
Q7	0	1	3	3	3	3.80
Q8	0	0	2	5	3	4.10
Q9	0	0	3	3	4	4.10

on moon observation in their daily life, which the mean of Q9 is 4.10.

In the questionnaire we also asked question that required participants to freely write down their opinions. 2 participants mentioned it would be better if we highlighted the horizon line and 1 user suggested that we use the arrow guidance to find the moon. We also asked participants what new feature they would like to see in the system. 3 participants suggested that it would be better to have a full moon reminder function. 3 users asked if it would be possible to include tidal information related to the lunar phase.

VI. CONCLUSION

In this study, we utilized the mobile AR technology and 2D content to construct multi-viewpoint observation environment for learners to observe lunar phases in the real-world environment without restrictions of weather, time, or place. The system has an AR view (to study the orbit, azimuth, height and circle of moon phases) and a Universe view (to help understand the mechanism of moon phases from the universe viewpoint) to support the learners with moon observation.

The results of the experiment revealed that the system was very usable and useful. Learners improved their learning and completed the set lunar observation learning goals using the M-VARML system. Furthermore, the M-VARML system enhanced students interest and motivation in observing moon phases in their daily life.

For future work, we plan to improve the interface design of the system so that even the learners with limited knowledge can use it and add more features, such as providing astronomy news about lunar phase. Further, our research group works in collaboration with Nagoya City Science Museum. Astronomy Curator plays a very important role in astronomy education. An important part of the future work includes discovery of ways to make best use of the knowledge of the curator in learning about the lunar phases. Our future challenges include the implementation of the M-VARML in a middle or high middle school science classes to test the learning effects of system.

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