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Practice and Evaluation with Planetary Simulator in Junior High School Science Classes

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Abstract: The planetary simulator can simulate planets' revolutions around the sun by fixing the viewpoint and point of gaze on any planet. We compared junior high school science classes using the planetary simulator (Class A) with a blackboard diagram (Class B) to represent the phases of Venus. In this study, 40 ninth grade (14–15 years old) students per class participated. Results of statistical analyses show that the planetary simulator enhanced students' understanding the phases of Venus more than a blackboard diagram. Most students evaluated the planetary simulator positively.

Keywords: Planetary simulator, junior high school, Venus, viewpoint, point of gaze, astronomical education, science education

Introduction

Traditionally, astronomy has been taught as a part of earth science in high schools in Japan. Especially, it is becoming important for students to understand structure and phenomena in the solar system, because nowadays it has been possible to survey the solar system by spacecraft, and also space industry will be important in near future. However, it is not easy for high school students to understand the structure and phenomena in the solar system, because it is impossible for them to see the structure and phenomena in the real sky with three dimensional views.

Considering such a background, several simulators with computer graphics have been developed for astronomical education. We briefly explain some simulators.

Simulators of solar system, galaxies and gravitational lens of black hole were made by 3D computer graphics, and then they have been used in a theater in Science Museum in Tokyo [1]. This has been known as science live show "Universe" supported by Chimons [2].

Astronomical VR Contents [3] can simulate the universe from the earth to the great wall galaxies like traveling by spaceship. Recently, tangible interface is made for solar system simulator to help children understand solar system more friendly [4].

As research on a method of expression of space phenomena with CG animation, the collision of the comet Shoemaker-Levy 9 with Jupiter in July 1994 is simulated [5].

Commercially available Stella Navigator [6] is an astronomical simulator produced by Astroarts co. ltd. It simulates night sky in any time and any place. It can simulate astronomical phenomena only from the earth viewpoint.

Furthermore, Mitaka [7], developed by the Four-Dimensional Digital Universe Project (4D2U Project) of the National Astronomical Observatory of Japan, runs simulations showing the perspective of a person traveling to the end of the universe, 13.7 billion light-years from Earth. By selecting a star from the menu, a learner can travel from the target star to the end of the universe. Planets, the moon, and several stars are prepared as target stars, and the distances from target stars are displayed for learners to be able to understand the size of each structure in the universe. This makes Mitaka excellent for understanding the contiguity from the solar system to the end of the universe.

Although those pieces of pioneering software have been developed, it is difficult to say that they have sufficient functionality required for general understanding of astronomical phenomena in the solar system, such as the waxing and waning of inferior planets and the passage of inferior planets across the solar disk.

Many astronomical phenomena in the solar system occur because of a certain positional relation between a target star and an observer. The biggest disadvantage of those pieces of software is that users cannot simulate astronomical phenomena in the solar system by fixing viewpoint or point of gaze on certain planet.

The planetary simulator [8] was developed by one of us, and is used in this study. It runs on Windows OS (Microsoft Corp.); it can simulate the motion of eight planets and a dwarf planet, Pluto, of the solar system in a virtual three-dimensional space in a personal computer. The advantage of planetary simulator is that it has a function for viewpoint setting and point-of-gaze setting activated by learners. The planetary simulator also has learning contents. Soga and others performed an evaluation of learning support effects of the learning content, the passage of Mercury across the solar disk, in a laboratory and reported the results [8]. However, no practical evaluation has been made at educational sites using the viewpoint setting function and point-of-gaze setting function of the planetary simulator. For this reason, we specifically examined the viewpoint setting function and point-of-gaze setting function, and developed a lesson including an activity that freely changed viewpoints in the space of the solar system.

1. Purposes

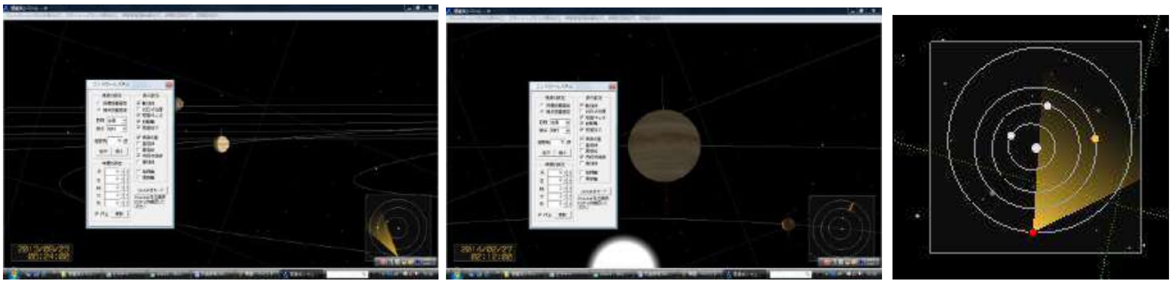
Purposes of the study were to implement and evaluate science classes at a junior high school, where a teacher gives demonstrative lessons to students using the viewpoint setting function and point-of-gaze setting function of the planetary simulator.

2. Methods

2.1 Overview of the planetary simulator

The planetary simulator has two fixing modes as the viewpoint setting function: one for viewpoint planets and the other for target planets as a point of gaze. The fixing mode for viewpoint planets can change a target point and observe the space of the solar system continuously while maintaining a given viewpoint fixed on a planet. Furthermore, by fixing a viewpoint on Earth and a target as a point of gaze on Venus, for example, a user can observe Venus as seen from Earth with tracking of Venus to be displayed always at the center of the screen. This is a new function that was not available satisfactorily in software used for the studies described earlier. The function enables a user to view the waxing and waning of Venus and view the changing apparent diameter of Venus as seen from Earth, as shown in Figure 1(a) and Figure 1(b). Moreover, simulation speeds of the revolution and rotation of a planet can be controlled on the control panel.

Figure 1(c) shows a miniature plan view that is displayed in the bottom-right square frame of the screen when seeing the solar system from “over” the North Pole. Furthermore, the positional relation between the sun, a planet (red point) as a viewpoint, and another planet (yellow point) as a target is displayed in real time in conjunction with the main screen. The angular range from a viewpoint indicated by pale yellow is the range being displayed on the main screen. When setting Earth as a viewpoint planet, the positional relation between Earth, planets, and the sun can be known by referring to this, as well as the apparent size and the waxing and waning of planets. The functions described above were used during lesson time.



(a) Venus is away from Earth (b) Venus is passing between Sun and Earth (c) Miniature plan view

Figure 1 Examples of Venus views seen from Earth

2.2 Practice Overview

This study was conducted for 2 hours. We introduced teaching practice in the area of the waxing and waning of Venus in the second field of science. Participants in the study were 80 students in two classes in the third grade of the attached junior high school, Faculty of Education, Shiga University: 40 students were studying in Class A (experimental group) and 40 students in Class B (control group). The teacher conducting lessons was the fourth author, who was in charge of regular science classes at that school.

Lessons were conducted for two credit hours. In the first period of the two hours, we taught a lesson to the experimental group using the planetary simulator and a lesson to the control group not using the planetary simulator. At that time, we conducted a problem-solving type questionnaire survey to investigate how much they understood about the learning content. We created survey sheets, called the investigation sheets for tasks, as one type each for pre- and post-surveys.

Next in the second period, we taught a lesson to the experimental group not using the planetary simulator and a lesson to the control group using the planetary simulator. We also conducted a survey by questionnaire to investigate how learners felt about the system. The prepared survey sheet was one type; this paper calls it a questionnaire survey.

Table 1 Flow of the practice

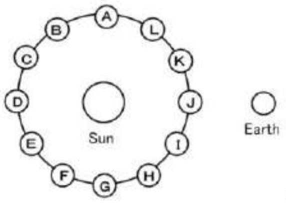
Date	Experimental group	Date	Control group
Dec. 10	Pre-survey	Dec. 4	Pre-survey
	Lesson A1 (Lesson with the planetary simulator)		Lesson B1 (Lesson without the planetary simulator)
	Post-survey		Post-survey
Dec. 12	Lesson A2 (Lesson without the planetary simulator)	Dec. 8	Lesson B2 (Lesson with the planetary simulator)
	Questionnaire survey		Questionnaire survey

Table 1 schematically presents the procedures of the survey. Because of the progress of lessons, the surveys of Class B (control group) were implemented on December 4 and 8; those of Class A (experimental group) were conducted later, on December 10 and 12.

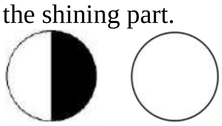
For a quantitative evaluation for learning effects with the planetary simulator, we conducted Lesson A1 for the experimental group and Lesson B1 for the control group. We gave Lesson

A2 and Lesson B2 to fill the gaps in final understanding between Class A and Class B, but did not use them for the quantitative evaluation for learning effects with the planetary simulator. However, we conducted the questionnaire survey after Lesson A2 and Lesson B2 had been completed. We sought responses after all subjects had experienced the differences between lessons with and without the planetary simulator. We extracted the contents of the investigation sheet for tasks shown in Figure 2(a) and Figure 2(b).

When seen from "over" the North Pole, Earth and the sun bear the relationship shown below.

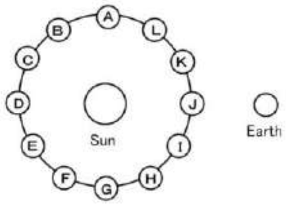


When Venus is regarded as the diagram below, at which position is Venus located? In this perspective, the white area is the shining part.



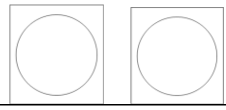
(a)Investigation sheet used for the pre-survey

When seen from "over" the North Pole, Earth and the sun bear the relationship shown below.



How is Venus with the following marks seen from Earth? Apply black to the area of a shadow.

1. Venus at B   2. Venus at L



(b) Investigation sheet used for the post-survey

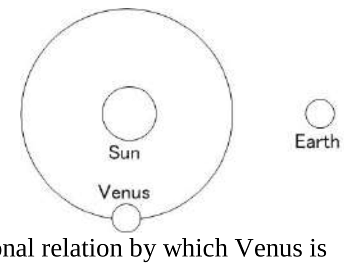
Figure 2 Investigation sheet used for the pre-survey and post-survey (extract).

2.3 Overview of "Lesson A1" and "Lesson B1"

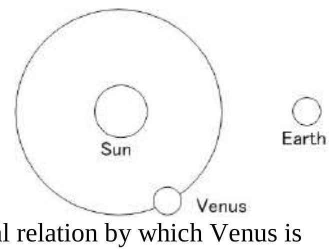
As Table 1 shows, we call the first period of lessons for the experimental group "Lesson A1" and that for the control group "Lesson B1", and used the planetary simulator in Lesson A1.

First, at the beginning of Lesson A1, we conducted a pre-survey with the investigation sheet for tasks related to the waxing and waning of Venus. Next, a teacher drew a half-moon-shaped Venus on the blackboard and had students think about the reason it showed that shape by asking "Let's explain why Venus looks half-moon shaped".

The teacher selected several students, who then explained their ideas. From among those presented ideas, the teacher selected the idea that is visualized as follows: Venus is seen as half-moon shaped when straight lines connecting Earth and the sun and connecting Venus and the sun intersect at right angles, as shown in Figure 3(a). Then, the planetary simulator was used to verify with whether Venus was regarded as half-moon shaped when the planets had such a positional relation.



(a) Positional relation by which Venus is NOT regarded as a half-moon shape



(b) Positional relation by which Venus is regarded as a half-moon shape

Figure 3 Positional relations and Venus's apparent shape when seen from Earth.

The procedures for verification were the following: Activate the planetary simulator, and move the viewpoint to "over" the North Pole. When lines to Venus and Earth from the sun form right angles, as shown in Figure 3(a), then time is stopped in the simulator. Then the relative position settings are left as is, and the viewpoint from Earth to the planet is fixed with the fixing mode for viewpoint of planets. We have set Venus as the target planet. Therefore, we observed the shape of Venus as seen from Earth.

At this point, results showed that Venus was not regarded as half-moon shaped.

Accordingly, we took the following procedures: we advanced time inside the simulator while keeping Venus in view from Earth; we stopped time inside the simulator when Venus became half-moon shaped. At the point, we changed the viewpoint with the fixing mode for target planets, and viewed the positional relation between Earth, Venus, and the sun from far "above" the North Pole. It was verified that straight lines connecting Earth and Venus and connecting the sun and Venus intersected at right angles (Figure 3(b)). That is to say, results showed that the straight line connecting Earth and Venus became a tangential line of the circle of the orbital path of Venus. The teacher selected some students to present what they found, and summarized the results on the blackboard. There were comments such as "Venus is not seen when it is behind the sun"; "Venus disappears when it is closest to Earth"; and "When being regarded as a half-moon shaped, Venus is on a tangential line of the orbital path." Finally, the teacher summed up the lesson by writing on the blackboard "The sun is on the brightly shining side." At the end of the lesson, we conducted a post-survey about the waxing and waning of Venus with the investigation sheet for tasks.

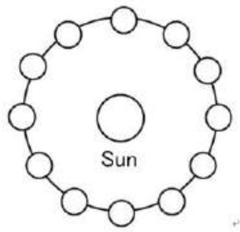


Figure 4 Diagram that the teacher drew on the blackboard in Lesson B1.

Meanwhile, we conducted Lesson B1 without the planetary simulator. First, at the start of the lesson, we administered a pre-survey about the waxing and waning of Venus using the investigation sheet for tasks with the same content for the experimental group. Next, a teacher drew a crescent-shaped Venus on the blackboard and asked "When Venus is regarded as this diagram, at which position is Venus located?" Students thought and presented their own ideas. The following comments were given: it is the position being "closer to Earth than the sun is", "far away or daytime", and so on.

The teacher drew 12 Venuses on the orbital path centering the sun on the blackboard (Figure 4) and explained, one by one, how each of the 12 Venuses was seen.

At the end of the lesson, we conducted a post-survey about the waxing and waning of Venus using the investigation sheet for tasks with identical contents for the experimental group.

3. Methods of analysis

3.1 Methods of analysis for the pre- and post-surveys

Eliminating absentee students, we analyzed 38 students in Class A and 39 students in Class B.

After giving "Lesson A1" with the planetary simulator and "Lesson B1" only with blackboard demonstrations, we examined the degree of difference between the results of task investigations, the waxing and waning of Venus, and between the experimental and control groups.

First, we calculated average scores for the pre- and post-surveys by class and assessed whether a significant difference could be inferred between them. A Wilcoxon signed-rank test was employed for this task.

For the experimental and control groups, we examined whether a significant difference was found in scores between the pre- and post-surveys. “Change in score” means subtracting the score in the pre-survey from the score in the post-survey. First, we calculated changes in scores in every subject of analysis. Subsequently, after dividing the students into the experimental group and the control group, we calculated averages of changes in scores for each group and assessed whether a significant difference was found between the averages of change in score in the experimental and control groups. A Mann–Whitney U test was used for this task.

Finally, calculating average scores of the entire class, we assessed whether a significant difference was found between the average scores of the experimental and the control groups in the pre-survey. Similarly, regarding the post-survey, we examined whether a significant difference was found between the average scores of the experimental and control groups. A Mann–Whitney U test was used for this task.

3.2 Questionnaire survey

The questionnaire comprised items with four choices and was quantified by rating on a scale of 1–4, where four is the highest. We calculated the averages of each class and then the standard deviation. In the questionnaire survey, we stated “Please specifically write down advantages and disadvantages of using the astronomical simulator when compared to not using it” and asked students for free descriptive answers. (In the lessons, the planetary simulator was called “the astronomical simulator” by the instructor.) Then we analyzed the free descriptive answers about the planetary simulator.

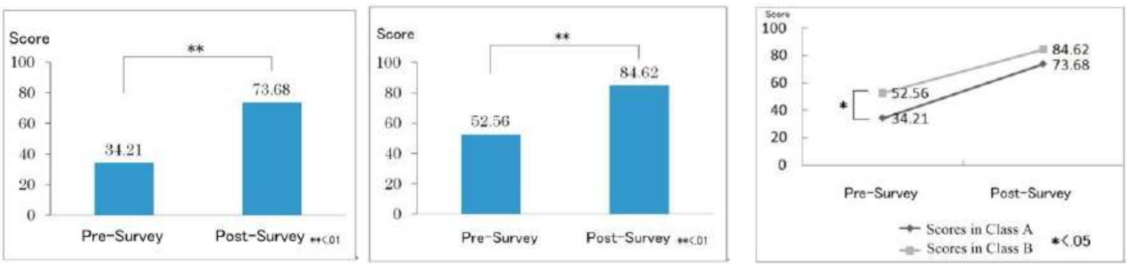
4. Results and study

4.1 Pre- and post-surveys

Table 2 portrays the average scores of the pre- and post-surveys by class. In both Class A (experimental group) and Class B (control group), a significant difference at the 1% level was inferred between the average scores of the pre- and post-surveys, as Class A, $p<0.0001$; Class B, $p<0.0001$ (see Figures 5(a) and 5(b)), which indicates the scores of tasks increased in both the experimental and control groups by Lesson A1 or Lesson B1.

Table 2 Average scores of the pre- and post-surveys

	Class	Average
Pre-survey	A	34.21 (*SD*＝35.08)
Pre-survey	B	52.56 (*SD*＝41.28)
Post-survey	A	73.68 (*SD*＝32.33)
Post-survey	B	84.62 (*SD*＝30.68)



(a)Average scores of Class A (b) Average scores of Class B (c) Improvements of Class A and Class B

Figure 5 Average scores of Class A and Class B in the pre- and post-surveys.

We calculated differences in scores between Class A and Class B between the pre- and post-surveys. The difference in scores is presented by subtracting the score in the pre-survey from the score in the post-survey.
We calculated the averages of changes in score in Class A and Class B, respectively: 39.47 points (SD=38.83) in Class A and 32.05 points (SD=42.12) in Class B. Although no significant difference in the average of change in score was found between Class A and Class B (p=0.4496), the average of the changes in scores was greater in Class A.
As Figure 5(c) shows, the average scores were higher in Class B both in the pre- and post-surveys than in Class A. However, although a significant difference between the scores of two classes in the pre-survey was found at the 5 percent level (p=0.0466), no significant difference was found between the scores of two classes in the post-survey (p=0.0688), which indicates that the scores in Class A reflected better improvement.

4.2 Questionnaire survey

We rated four choices for an item of the questionnaire on a scale of 1–4, where four is the highest. To the question of "How did you find the activity using the astronomical simulator in science classes?" all students in Classes A and B gave positive comments: The average in Class A was 3.87 (SD＝0.23); the average in Class B was 3.73 (SD＝0.41). Furthermore, to the question of "Was the lesson using the astronomical simulator easy to understand?" all students in Classes A and B gave positive comments: The average in Class A was 3.94 (SD＝0.28); the average in Class B was 3.75 (SD＝0.41).
Many students who answered about the lessons used the planetary simulator, remarking that it was "enjoyable" and "easy to understand", which indicates that students had positive views about the lessons with the planetary simulator.
As for comments on "advantages" of the planetary simulator given in the free description part of the questionnaire, we introduce the following as examples: "It can be seen with eyes. It is easier to get a mental image because I cannot see stars from my house." (student N in Class A); "It is easier to understand what is being presented in text books. It is easier to have images in my head." (student I in Class B); "Because viewpoints were changeable, I understood Venus as seen from Earth very well." (student K in Class A); and "Because viewpoints and targets are changeable, it is very convenient" (student K in Class B). We think that students understood the learning contents visually and found it easier to imagine planets through the lessons using the planetary simulator.
Furthermore, there were descriptions as follows: "It was easier to understand the motion of stars because they actually moved." (student O in Class A); "Because it is three-dimensional, it is easy to understand. The positional relations of planets were easy to understand" (student K in Class A); and "Proportions of planets are easy to understand. Viewpoints and targets are changeable. The movement on each date is understandable." (student T in Class B). We consider that the following facts supported students to change their viewpoints: planets can be moved quickly and on site through operation by a teacher; moreover, the positional relations among planets after the movement are understandable.
On the other hand, as for the comments on "disadvantages" of the planetary simulator, students who answered that "There are operability problems" were four in Class A and 30 in Class B. As well as comments that "It seemed difficult to operate." (students K and F in Class B, etc.), "It takes time to prepare." (student M in Class B), and "It takes time to operate." (student F in Class B), there were comments such as "It cannot be rewound." (students Y and W in Class A, etc.). It can be rewound to the scene where one wants to see again, even if it is missed, because the planetary simulator can display a specific scene at a particular time. However, the teacher did not use the function during lessons.
Students who left response areas blank or wrote "none" about "disadvantages" were 27 in Class A and one in Class B. In the free description part of the questionnaire related to

disadvantages, the number of students in Class A who "left blank or answered as none" was nearly equal to the number of students in Class B who gave comments that "There are operability problems." We interpret this as the following: Lesson A1 for Class A was conducted after Lesson B2 for Class B; and because a developer instructed the teacher how to operate the simulator briefly during the lesson for Class A, the teacher was more familiar with the operation of the simulator in the lesson for Class A. Consequently, the students who remarked about operability problems were fewer in Class A.

Results show that, despite some anxiety about the operability of the simulator, students thought that the planetary simulator would support learning. Moreover, results suggest that the operability of the planetary simulator must be examined.

5. Conclusions

This study was undertaken to evaluate the planetary simulator as a teaching aid to support learning in the astronomical domain of school education. We conducted lessons using different methods to teach third grade students of a junior high school about the waxing and waning of Venus. The lessons were given in classes with the planetary simulator and only with blackboard demonstrations. We analyzed task investigations of Venus that were conducted before and after the lessons. In both classes, scores increased after the lessons, but improvement rates were greater in the lessons using the planetary simulator. We also conducted a questionnaire survey in the lessons using the planetary simulator. Results revealed that students surveyed regarded the viewpoint setting function of the planetary simulator generally approvingly, which suggests that the viewpoint setting function of the planetary simulator supports learning about planets at a practical level. Students who observed the teacher's demonstrations judged the viewpoint setting function approvingly.

However, the free descriptions of the questionnaire showed that some students were anxious about the simulator operability. We think that some improvements, such as enhanced help functions explaining how to operate the simulator, are needed when using the planetary simulator in class.

The authors feel that learning should not end by recognizing a starry sky seen on the simulator as some artificial phenomenon. The lesson development should be devised in collaboration with outdoor observation activities. For example, understanding of the waxing and waning of Venus might be enhanced considerably by watching Venus during daytime and combining observations to study the shapes and the positional relation with the sun.

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