Learning by Tangible Learning System in Science Class

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Abstract. Tangible User Interfaces are one of the ideas to develop a learning materials as an invisible computing system. First, we developed a tangible learning system for learning Solar System that allows the users themselves to manipulate astronomical models of the sun, earth, and moon, which exist as visible tangible bodies. Second, the tangible learning system was implemented in an elementary school science class and twenty 6th grade students from a public elementary school participated in this practical study. The results clearly showed that the comprehension test scores of students who scored high on mental rotation test increased greatly following the class using the tangible learning system.

Keywords: Tangible user interface · Science class · Mental rotation

1 Introduction

The astronomy area of science courses is one of the most difficult contents for teachers to teach in classroom. In the same way, it is not easy for students to understand the positional relationships of celestial bodies rotating in relative motion [1–3]. To imagine the movement of the relative positional relationships with an awareness of the positional relationships of celestial bodies, it is necessary to mentally shift their viewpoint and shape dynamic images into a mental model [4–7].

There has been research into the effectiveness of astronomy learning materials using physical models and video contents in order to indicate the scenes in space. Computer simulations can be presented a virtual space as three-dimensional (3D) dynamic images that cannot be observed in the real world, so students can learn the phenomena from a variety of angles in the space [8–11].

However, the previous astronomy learning materials that formed the basis for celestial body simulations were unable to touch and operate the 3D computer graphics (CG) relative positional relationships of the sun, earth, and moon. The learners can become observers of natural phenomena within the virtual space;

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however, in many cases, they are unable to actively interact with the CG model, or observe after shifting to different viewpoints. For elementary school students, manipulating models in physical space and actively observing the phenomena from various angles will provide a more effective learning environment.

A tangible user interface (TUI) is technology that makes it possible to operate models in physical space to promote learning [12–15]. As for studies of astronomy learning to which TUI was applied, there is the development of a tangible globe system supporting viewpoint shifts in a learner using an avatar [16–18]. Also, an astronomy learning content that could be operated intuitively were developed for science classes [19].

Morita *et al.* [20] applied augmented reality technology to develop a tangible learning system in which virtual models in the virtual learning environment and physical models in the real learning environment seamlessly move in conjunction. There has also been practical research where the systems have been introduced in elementary school and junior high school classrooms [21,22]. In this paper, we focus on the relationship between the mental rotation ability of 6th grade elementary school students and comprehension tests, and discuss the benefits and problems of the tangible learning system.

2 Development

2.1 Design

The tangible learning system was designed to support collaborative learning in classroom [20]. The learners operate concrete objects on a table in physical space, while shifting their viewpoint in virtual space, and discussing the waxing and waning of the moon, and the positional relationships between the sun, earth, and moon. Furthermore, the learners themselves are able to recreate the movement of the celestial bodies, rotating in relative motion, and the phenomena they cause (for example, the eclipse) in their own mental space, and carry out activities such as shifting viewpoints to the desired position and performing observation.

The thing given most attention to during system design was not the simulation, but the reproduction of learning focusing on shifting viewpoints within the simplified virtual space. The astronomical 3D CG model in this system does not fix the positional relationships in the virtual astronomical model as shown in the previous simulations and does not perform rotational linking of rotating and revolving. For this reason, learners can move the model actively while searching for astronomical positional relationships and rotating and revolving manually.

Furthermore, the earth's axis in the global model within the virtual space is set vertically in relation to the revolving surface (inclined at a 23.4° angle in relation to the physical revolving surface of the earth's axis. For this reason, although the seasonal changes in the south altitude and meaning of tropics cannot be demonstrated to the learner, it is possible to focus learning on the phase of the moon. In addition, in this system, it is set so that the revolving orbit plane of the earth and revolving orbit plane of the moon do not overlap, to present a full moon or new moon. For this reason, when reproducing phenomena such as a solar eclipse or lunar eclipse, the operation of lifting the celestial bodies from the table to the air is required.

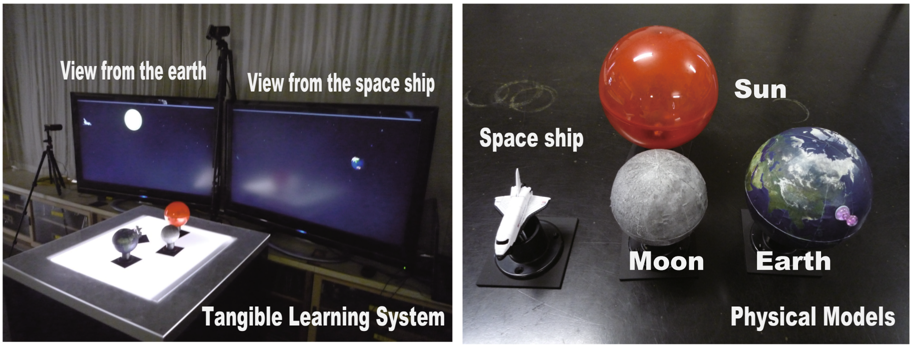

Fig. 1. External appearance of the tangible learning system and physical models

2.2 Hardware

Figure 1 shows the external appearance of the developed tangible learning system and the physical models used in manipulations by the students. In this paper, we call the model that they can actually touch the physical model, and the 3D CG objects within virtual space the virtual model. The reason for adopting a table-top interface is that a scenario is envisaged in which the students learn collaboratively and exploratorily in groups while operating the physical models. The physical models envisage learning of the waxing and waning of the moon in the science class, and the models has prepared the sun, earth, moon, and a space ship. The reason for including the space ship model is to encourage exploratory activities and set viewpoints for observing celestial bodies in outer space.

The respective sizes of the physical models, in the same way as other simulation learning materials, was not scaled down based on the physical size. Sizes that were considered to be suitable to be physically operated by elementary and middle school students were selected.

2.3 Software

Figure 2 shows an overview of the processing carried out by the tangible learning system. The system recognizes the black and white rectangular image known as the marker, stuck to the reverse side of each physical model placed on the table, and determines the global coordinates in the virtual space and the local coordinates for each marker. It then calculates how it is viewed from virtual cameras (invisible and not displayed as images on the display) installed in each virtual model within the virtual space and outputs that image to the display. As these processes are processed in real-time, they are linked to the operations of the physical model and enable interactive operations of the virtual model. Furthermore, to realize multi-viewpoint learning, images seen from any two viewpoints at the same time can be presented respectively on two displays.

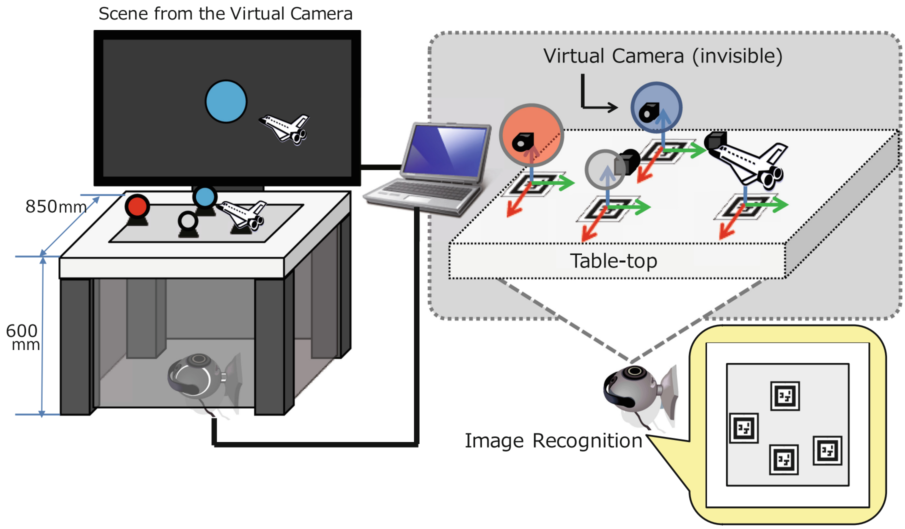

Fig. 2. Processing of tangible learning system

3 Evaluation

3.1 Practical Research in Science Classes

Overview of Target and Procedure. In this study, we carried out science classes on the waxing and waning of the moon using the developed tangible learning system aimed at twenty 6th grade public elementary school students (13 boys and 6 girls).

Figure 3 shows the procedure of practical research in the science classes. The classes were held three times, for two class period (90 min) each, over approximately four weeks. Furthermore, all practical classes were conducted by a full-time elementary school science teacher. For group activities using the tangible learning system, teacher instruction and student activities were recorded from the top of the table and left the side of the display.

Group Activities Based on Image Presentation. The first class was a teacher-centered class mainly using video and CG contents. Firstly, the teacher indicated a hi-vision video captured by lunar probe *Kaguya* on a large-scale liquid crystal display to make the students consider the positional relationship between the sun and the earth. Next, in order to compare the size of the sun,

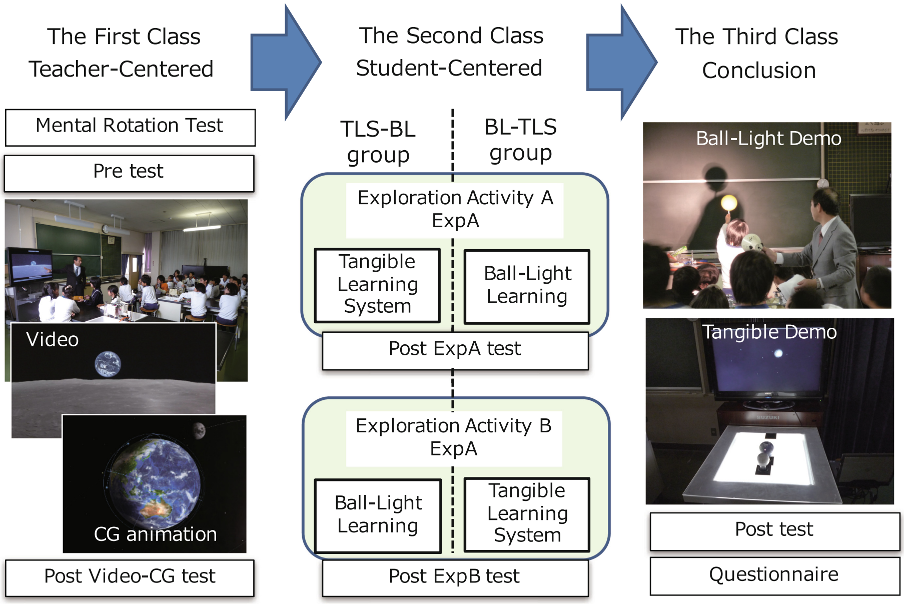

Fig. 3. Procesure of practical research in 6th science class

earth, and moon, CG images of the solar system planets were presented on the display. Then, revolving and rotating images of the earth and moon was presented to explain the positional relationships with the sun. Finally, the phase of the moon presented by CG animation.

Exploratory Learning in Groups. In the second class, the students were divided into two groups and using tangible learning system configured four physical models and two displays and ball-light learning materials using a light. They learned the mechanism of the waxing and waning of the moon in an explorative way. The students were divided into two groups because, when the tangible learning system was designed, it was envisaged that it would involve collaborative and explorative activities by up to a maximum of 10 people. The group first learning in an explorative way using the tangible learning system, and then using ball-light learning materials was named the TLS-BL group, and the group learning in the reverse order was called the BL-TLS group. The exploratory activities carried out in the first half were called "ExpA" and when carried out in the second half, the exploratory activities were named "ExpB."

The exploratory learning with the tangible learning system and the exploratory learning using the ball-light learning materials were each carried out for 30 min. With the exploratory learning using the tangible learning system, the science teacher moves physical models of the sun, earth, moon, and space ship by hand for the students, while performing an experiment to make students think about the movement of celestial bodies in virtual space. Next, the students take the lead role in operating the tangible learning system and displaying and confirming the phases of the moon, which can be observed from the viewpoint of an earth virtual model or space ship virtual model. When engaging in exploratory learning using the ball-light learning materials, the students, with the support of the teaching staff, irradiated a light on a sponge-shaped ball and observed the shadows. The students fixed the ball and light (their own eyes provide a bird's eye viewpoint) and, while taking the ball in their hands and rotating this in front of the light (their own eyes provide an earth viewpoint), they sketched an image of the lunar phases on the worksheet.

Class Summary. In the third class, the teacher summarized the first and second classes. At this time, based on the activities during the second class, only the two physical models of the earth and moon were used, and the learning content was provided with the tangible learning system in a one display configuration (by referencing interactive analysis results for group activities using the tangible learning system). The instructor, using the tangible learning system and ball-light learning materials, explained in detail the mechanism of the phase of the moon while switching between demonstrations. We then presented again the images of the moon surface captured by a lunar probe that was presented in the first class, to make the students reconsider the positional relationships of the sun, earth, and moon.

3.2 Measurement

We executed a Mental Rotation Test (MRT) [23,24] consisting of 20 questions at the start of the first class to measure the ability of the individual learners to mentally rotate shapes. Also, a comprehension test has performed a total of 5 times and all had the same questions. The first test was performed at the start of the first class (Pre test), and the second one was done after the class in which the image materials and CG materials are presented in the first class (Post Video-CG test). After the exploratory activities A (TLS-BL group used the tangible learning system, and the BL-TLS group using the ball-light learning materials) in the second class, the third test was performed (Post ExpA test), and the forth test (Post ExpB test) was done after the exploratory activities B (TLS-BS group using the ball-light learning materials and the BL-TLS group using the tangible learning system). In the third class, students took the last test after the summary (Post test). To answer the respective questions correctly, it was necessary to imagine the classroom activity scenarios, shift viewpoints within mental space, and operate mental models dynamically.

In the comprehension test, we used two questions for six points in regard to shifting viewpoints exhibiting a ball shadow in physical space, two questions with four points exhibiting the earth's shadow (static image) in virtual space, two questions with four points exhibiting the shadows of an physical model of the moon observed between an physical model of the earth and physical model of a space ship placed on a table in physical space (static image) and 2 questions with four points with selective answers on the phases of the moon seen from the earth in virtual space in relative rotational motion, for a total of 18 points.

3.3 Analysis

The mean values of MRT points were calculated, and the students were divided into the MRT upper group and MRT lower group. Then, three-way analysis of variance (ANOVA) was performed the groups during exploratory activities and relationship with the comprehension test scores. The first factor was MRT (upper and lower groups), the second factor was exploratory activities (TLS-BL and BL-TLS groups), and the third factor was the test period (Pre test, Post Video-CG test, Post ExpA test, Post ExpB test, and Post test).

3.4 Results

Comprehension Test. Figure 4 shows the result of the mean scores for the both TLS-BL and BL-TLS divided into the MRT upper and lower groups. The results of the three-way ANOVA show that the secondary interaction effect was insignificant at the 5% level ($F = 0.72$, $df1 = 4$, $df2 = 64$, *n.s.*). Furthermore, the primary interaction effects between MRT and exploratory activities and the exploratory activities and test period were not significant either ($F = 0.05$, $df1 = 1$, $df2 = 16$, *n.s.*; $F = 0.14$, $df1 = 4$, $df2 = 64$, *n.s.*). The main effects of the exploratory activities were significant at the 5% level ($F = 4.70$, $df1 = 1$, $df2 = 16$, $p < .05$). Based on this, it is clear that there was a significant difference between the TLS-BL group and BL-TLS group, regardless of factors such as MRT and test period.

On the other hand, the primary interactive effects between MRT and the test period was significant ($F = 4.35$, $df1 = 4$, $df2 = 64$, $p < .01$). Therefore, the result of performing lower level analysis using Ryan's Method was that in the test, after the exploration activity A, the test after the exploration activity B, and in the post test, there was a significant difference between the mean values in the MRT upper and lower group comprehension test scores ($F = 6.12$, $df1 = 1$, $df2 = 16$, $p < .05$; $F = 5.79$, $df1 = 1$, $df2 = 16$, $p < .05$; $F = 4.58$, $df1 = 1$, $df2 = 16$, $p < .05$). In other tests, there was no significant difference between the MRT upper group and lower group. Furthermore, in the MRT upper group, a significant difference was seen between the scores for the test after the exploration activity A, the test after the exploration activity B and post test and the respective pre tests ($Mse = 2.80$, $df = 64$, $p < .05$). In the MRT lower group as well, a significant difference was seen between the post test scores and pre test scores ($Mse = 2.80$, $df = 64$, $p < .05$).

The following four points are clear based on the above results; The BL-TLS group, when compared to the TLS-BL group, had significantly high comprehension test scores from those before the class. After receiving the classes in which Video and CG are presented, the comprehension test scores were significantly improved. The students in the MRT upper group after performing exploratory learning, using the tangible learning system or ball-light learning materials, had significantly improved test scores. The MRT lower group, after taking 3 classes, had improved comprehension test scores.

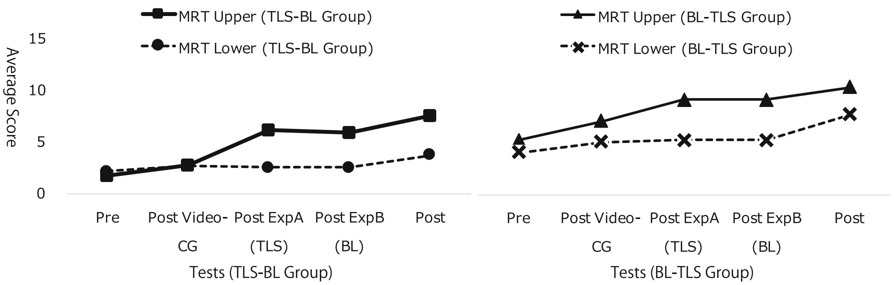

Fig. 4. Comprehension test scores

Group Activities. We analyzed the interaction during group activities using the tangible learning system. From these results, we learned that, with the 2-screen configuration tangible learning system, it took time for the students to understand what images were being presented from which viewpoint by which display. Furthermore, in the dialogue shown below, the following three points have been clarified: the prompting of collaborative learning, the issue of the sun model being a point light source, and the fact that there are students that play with the physical model of the space ship.

The Prompting of Collaborative Learning. The students collaboratively explored positional relationships with images in groups, with images of the new moon, the crescent moon, half-moon, and full moon. At this time, using this system, a dialogue took place to understand the phenomena of the moon phases. An example of the dialogue is shown below as the evidence of collaboration.

Student A: It's a full moon.
Student C: Yes, if you move it more that way...
Student A: It's a full moon, this.
Student E: Not yet.
Student A: I think it is OK now.
Student C: Full moon.
Student A: A perfect full moon.

Issue of the Sun Model as a Point Light Source. As, in this system, the sun was set as a point light source, it was not possible to reproduce a half-moon accurately. Therefore, cognitive conflicts might occur in some students, and some scenarios in which understanding was not promoted were seen. This is shown in the following dialogue.

Student N: Hey, this is a full moon.
Student L: How about a half moon? Or crescent moon?
Student N: Half-moon... I don't know what a half moon is.
I could do a crescent moon, though.
Student L: Where did the space shuttle go? OK, then I will be the space shuttle.
Student K: Crescent moon? Half-moon... like this, see...
Student N: Hey, this is not half. Do a bit more... a bit more <unclear>.
...
Student L: Hey, space shuttle. This isn't working out to be a crescent moon.
Student N: Right next to it.
Student O: Like this?
Teacher: Yes, yes, yes
Student M: So, this is not a half moon.

Students that Play with the Physical Space Ship Model. The physical space ship model was introduced as a viewpoint to project, with a bird's eye view, the phenomenon of the phases of the moon. However, there were students who were interested in the physical space ship model and who engaged in actions that were completely unrelated to the classes. An example of the dialogue is shown below.

Student M: It's broken... No, no, no.
Student L: Stop, moon, moon, moon ...come on!
Teacher: Hang on···. I'm feeling sea sick. Stop it.

Above, we described some of the dialogue of the students operating the tangible learning system. The students conducted exploratory activities related to the phases of the moon. This system could prompt collaborative learning among the learners. On the other hand, the model of the sun in this system impeded students' understanding. Additionally, it is clear that there were many scenarios where the physical space ship model was used for objectives other than those related to the class.

4 Discussion

4.1 Effectiveness of the Tangible Learning System

From the results of the comprehension test, it can be said that the tangible learning system was effective for students with mental rotation skills, but not so much for students without such skills. Below, the TLS-BL group and the BL-TLS group will be discussed separately.

In the TLS-BL group, after taking the first class with Video and CG animation contents, the scores for the comprehension test were not significantly improved. In the second class, after the exploratory activities using tangible course materials, the comprehension of the MRT upper group students was significantly improved. From this fact, it is suggested that exploratory activities using the tangible learning system are effective. However, following this, an improvement in comprehension was not seen using the ball-light learning materials.

For the BL-TLS group, in the same way, after taking the first class with Video and CG animation contents, the comprehension test scores were not significantly improved. In the second class, after the exploratory activities using the ball-light learning materials, the comprehension in the students in the MRT upper group was significantly improved. This suggests that the exploratory activities using the Ball-Light course materials are effective; however, there was no improvement in comprehension seen through activities(ExpB)using the tangible learning system after this.

From these results, in regard to the MRT upper group, it is suggested that there may be an impact on the learners on the improvement in active and exploratory activities. The fact that no improvement was seen in ExpB for either the TLS-BL group and BL-TLS group may be due to the ceiling effect. This point requires careful discussion. On the other hand, in regard to the MRT lower group as well, there was no improvement in comprehension level even when using Video and CG animation teaching materials, tangible course materials, and light materials. In regard to the summary in the 3rd class, as a result of the detailed explanation by the teaching staff, comprehension was improved in comparison to before the class. This suggests that a certain amount of time for repeating an explanation may be required to improve the comprehension of students with comparatively low mental rotation skills.

4.2 Points of Improvement for the Tangible Learning System

From the interactive analysis results, it is clear that there are some light source issues and physical model issues in the tangible learning systems. We shall move forward with the discussion of both of these respectively.

The issue with the sun model as a point light source is essentially the same issue with the tangible learning system and ball-light learning materials. Differences in the sun and earth were taken up in the first class. However, they are different to the point light sources of model and light; there were students who could not imagine light as a parallel light source from large fixed stars such as the sun. As shown in the dialog, this was thought to cause cognitive conflicts in the students so comprehension could not be promoted. In this implementation, this issue was noticed when executing the second class. Therefore, in the third class, the class was carried out with the physical solar model excluded. Furthermore, the instructors emphasized and explained that the sun is much bigger than the earth and the moon and that it exists as a parallel light source in relation to the earth and the moon.

The issue with the space ship physical model is not essentially a problem and not a problem with the system. This was physically a problem with the physical model in front of us. In the case of elementary school students, the space ship model was attractive as a toy. It was clear that there was an essential problem we had not grasped in that this may have distracted attention from the content of the class. In the same way as the sun model, the issue in the space ship physical model was learned while conducting the second class. In the third class, the class was executed with the sun model excluded.

5 Summary

In this paper, we investigated the effectiveness of the developed tangible learning system in an elementary school science class on the phase of the moon. The results of ANOVA were that for students with comparatively high mental rotation skills, the learning content could be understood through active and exploratory activities using the tangible learning system. Improvements in comprehension test scores meant that a mental model had been formed in the mental space. It was considered that the group with high MRT scores, that is to say, students who, comparatively, had acquired the mental rotation skills, learned in an exploratory way, linking real space and virtual space, and formed a mental model related to the waxing and waning of the moon. Comprehension improvements in students with comparatively low mental rotation skills required a certain amount of time and repetition of explanation. Issues moving forward include long-term views, from elementary school to junior high school, investigating learning using the tangible learning system.

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References

1. Nussbaum, J., Sharoni-Dagan, N.: Changes in second grade students's preconceptions about the earth as a cosmic body resulting from a short series of audio-tutorial lessons. Sci. Educ. **67**(1), 99–114 (1983)
2. Vosniadou, S.: Conceptual development in astronomy. In: Glynn, S., Yearny, R.H., Britton, B.K. (eds.) The Psychology of Learning Science, pp. 149–177. LEA, NJ (1991)
3. Suzuki, M.: Conversations about the moon with prospective teachers in Japan. Sci. Educ. **87**(6), 892–910 (2003)
4. Taylor, I., Barker, M., Jones, A.: Promoting mental model building in astronomy education. Int. J. Sci. Educ. **25**(10), 1205–1225 (2003). doi:10.1080/0950069022000017270a
5. Shen, J., Confrey, J.: From conceptual change to transformative modeling: a case study of an elementary teacher in learning astronomy. Sci. Educ. **91**(6), 948–966 (2007). doi:10.1002/sce.20224
6. Plummer, J.D., Wasko, K.D., Slagle, C.: Learning to explain daily celestial motion: understanding astronomy across moving frames of reference. Int. J. Sci. Educ. **33**(14), 1963–1992 (2011). doi:10.1080/09500693.2010.537707
7. Türk, C., Kalkan, H., Kiroğlu, K., İskeleli, N.C.: Elementary school students mental models of formation of seasons: a cross-sectional study. J. Educ. Learn. **5**(1), 7–30 (2016). doi:10.5539/jel.v5n1p7

8. Barnett, M., Yamagata-lynch, L., Keating, T., Barab, S.A., Hay, K.E.: Using virtual reality computer models to support student understanding of astronomical concepts. J. Comput. Math. Sci. Teach. **24**(4), 333–356 (2005)
9. Morita, Y., Iwasaki, T., Takeda, T., Fujiki, T.: Portable immersive projection technology system for 3D visual learning. In: Proceedings of ED-MEDIA, pp. 2585–2588 (2006)
10. Setozaki, N., Morita, Y., Takeda, T.: Examination for the practical use of screen presentation systems and VR teaching material. In: Proceedings of the SITE International Conference, pp. 3488–3494 (2007)
11. Sun, K.L., Wang, S.C.: A 3-D virtual reality model of the sun and the moon for e-learning at elementary schools. Int. J. Sci. Math. Educ. **8**(4), 689–710 (2010)
12. Ishii, H., Ullmer, B.: Tangible bits: towards seamless interfaces between people, bits, and atoms. In: Proceedings of CHI, pp. 234–241 (1997)
13. Schneider, B., Wallace, J., Blikstein, P., Pea, R.: Preparing for future learning with a tangible user interface: the case of neuroscience. IEEE Trans. Learn. Technol. **6**(2), 117–129 (2013)
14. Schneider, B., Blikstein, P.: Unraveling students' interaction around a tangible interface using multimodal learning analytics. J. Educ. Data Mining **7**(3), 89–116 (2015). doi:10.1109/TLT.2013.15
15. Cuendet, S., Dehler-Zufferey, J., Ortoleva, G., Dillenbourg, P.: An integrated way of using a tangible user interface in a classroom. Int. J. Comput.-Support. Collab. Learn. **10**(2), 183–208 (2015). doi:10.1007/s11412-015-9213-3
16. Yamashita, J., Kuzuoka, H., Fujimon, C., Hirose, M.: Tangible avatar and tangible earth: a novel interface for astronomy education. In: Proceedings of CHI, pp. 2777–2782 (2007). doi:10.1145/1240866.1241078
17. Yamashita, J., Nishikawa, S., Kuzuoka, H.: Tangible earth: a novel interface for astronomy education. In: Proceedings of ASIAGRAPH, pp. 206–209 (2008)
18. Kuzuoka, H., Suzuki, Y., Yamashita, N., Kato, H., Suzuki, H., Kubota, Y.: Thoughts on design principles for tangible learning environment for astronomy education. J. Sci. Educ. Japan **38**(2), 65–74 (2014). doi:10.14935/jssej.38.65. (in Japanese)
19. Kawasaki, T., Iwane, N., Matsubara, Y., Okamoto, M.: Development of a VR-based astronomy learning environment using intuitive manipulation and switching of the view corresponding to user's body movement. Educ. Technol. Res. **34**(1/2), 173–180 (2011)
20. Morita, Y., Setozaki, N., Iwasaki, T.: Development and evaluation of a tangible learning system for astronomy education: a pilot study. In: Proceedings of ED-MEDIA, pp. 3666–3671 (2010)
21. Morita, Y., Setozaki, N.: Practical evaluation of tangible learning system: lunar phase class case study. In: Proceedings of SITE International Conference, pp. 3718–3722 (2012)
22. Morita, Y., Setozaki, N.: Science class using interactive multimedia and tangible learning system: a pilot study. In: Proceedings of ED-MEDIA, pp. 2929–2934 (2012)
23. Shepard, R.N., Metzler, J.: Mental rotation of three-dimensional objects. Science **171**, 701–703 (1971)
24. Samsudin, K., Rafi, A., Hanif, A.S.: Training in mental rotation and spatial visualization and its impact on orthographic drawing performance. J. Educ. Technol. Soc. **14**(1), 179–186 (2011)