Thoughts on Effective Learning Procedure for Tangible Learning Environment Based on Embodied Design

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Abstract. Based on an observational study of astronomy education using a tangible globe system, this paper aims to elicit implications for effective learning procedure for tangible learning environments. By analyzing the experiment based on "embodied design" concept, we found that, when appropriate instruction is not provided, intuitive operability of tangible user interface at times rather disturbs learners' thinking opportunities. We also found that by properly limiting the information to show learners, the system can make learners be more conscious of the meaning of manipulating tangible objects and result in better understanding of the learning content.

1 Introduction

Grasping the concepts related to earth-sun relationships is difficult since students need to deal with immense scales and combine knowledge from various perspectives [15]. For example, they need to understand how the spatiotemporal relationships between the sun and the earth cause daily and seasonal variations to fully understand the sun's diurnal motion [8, 11]. Atwood and Atwood reported that even some preservice elementary school teachers fail to understand these relationships [2].

In this paper, we adapt a tangible user interface (TUI) approach to support astronomy education. Since globes effectively help students grasp basic astronomy concepts [2, 8, 14], we believe that expanding the tool's capability to provide multiple perspectives is a promising approach for astronomy education. While many studies have applied TUIs for educational purposes (e.g., seismology [7], basic programming [12, 17], and vocational training [10]) and demonstrated their benefits in collaborative learning [5, 16], few have applied them to astronomy education [8].

With the TUI approach, we developed a tangible learning environment (TLE) called the tangible globe system (Figure 1) to support the learning of earth-sun relationships. Our system consists of a tangible globe, a tangible avatar, an electric light, and a PC screen that shows a computer-simulated view from the tangible avatar. The spatial arrangement of these components fosters learners to observe multiple perspectives of such earth-sun related phenomena as a birds-eye-view of the solar system and a computer-simulated ground-level view.

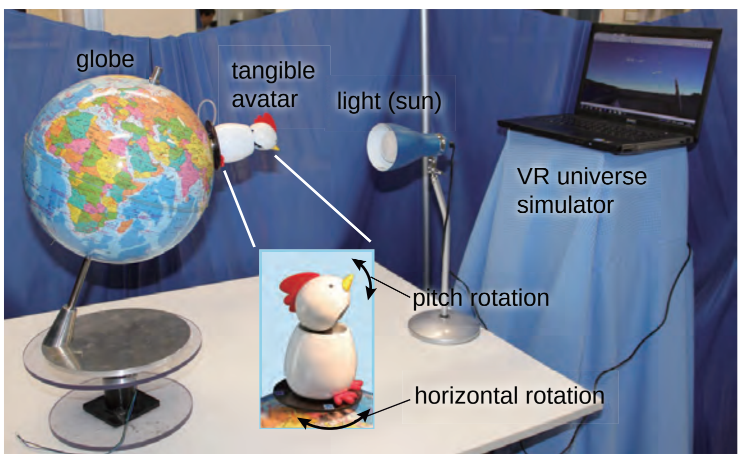

Fig. 1. Overview of Tangible Globe system

We have been empirically applying our system in regular/extracurricular junior high science classes. Although most of the students and teachers were enthusiastic about the system, we also observed instances where it was not embraced. Our controlled experiments have barely shown its clear benefit over traditional methods that only use a simple globe.

To better understand our system's problems and to propose design implications to improve them, we chose a design-based research approach [3] and observed how the system impacted learning practices. Through these experiments, we came to realize that not only the system but also the study method is important. Based on these experiences, this paper aims to discuss the effective learning procedure design which can make use of the TLE more effectively.

2 Framework

2.1 Design-Based Research

Design-based research (DBR) was developed to compensate for the limitations of traditional laboratory studies. According to Collins et al., "Laboratory studies are effective for identifying effects of particular variables, but they often neglect critical values to the success of" [3] educational intervention. To compensate for this limitation, design-based research is carried out in actual learning environments, and ethnographic techniques are often used to understand what is happening in the field and how.

The goal of design-based research is twofold: designing effective learning environments and developing general theories of learning. "Continuous cycles of design, enactment, analysis, and redesign" [4] allow researchers to effectively achieve these goals.

2.2 Embodied Design

Abrahamson and Lindgren proposed 'embodied design' concept to guide designing learning environment for science, technology, engineering, and math [1]. According to them, when one cannot achieve the desired effect despite a trial to achieve a certain goal using a physical tool, he/she conciously reflect on how we used the tool and recalibrate the usage of the tool to achive the goal. Such thinking and re-adujusting process is certainly a learning. The important thing about the learning tool is not to let learners use the tool unconsciously without thinking of the meaning of the operation, but to let them analyze how they are interacting with the tool themselves and to make them understand concretely and quantitatively. By doing this, the behaviors with respect to the tool is gradually internalized within the learners. Then, even without the tool, it becomes possible for them to simulate the behavior against the tool, or even to simulate the motion in their mind.

What is important here is to design a learning tool that makes it possible to understand its meaning during performing trial and error process on an artifact, and gradually internalize the body motion. Furthermore, it is pointed out that a teacher's proper scaffolding is important in making the learning tool effective.

Based on these ideas, this paper clarifies how the learners' actions to the tangible globe system affect the understanding of learning contents. We then discuss the appropriate learning procedure that makes the tangible learning environment effective.

3 Past studies with Tangible Grobe System

3.1 Tangible Globe System

Based on the concept of TUI, the authors developed the tangible globe system to support the learners to understand the spatio-temporal relationship between the sun and the earth [13].

Our TLE, called the tangible globe system, was designed to support the learning of the relation of the sun's diurnal motion and the earth's rotation. It consists of a doll-like figure (tangible avatar or avatar), a globe, a rotating table, an electrical light, and a laptop PC (Figure 1). The electrical light represents the sun. The laptop runs a publicly available VR universe simulator, Mitaka [18] to show the diurnal motion of the sun in the celestial sphere (ground-level view).

The globe is rotated around the earth's axis either forward or reverse during the simulation to change the sun's position in the celestial sphere. Rotation of the globe is detected by a rotary encoder inside the globe. DIN type connectors are embedded at the locations of Japan, Australia, and Honduras to plug the avatar into those places and to change the location of the ground-level view. The avatar's body rotation angle and pitch rotation angle are detected by potentiometers embedded in the avatar. The information of the globe rotation, the avatar's position, and the avatar's posture is captured by a PIC16F876 microcontroller and wirelessly sent to a note PC using ZigBee protocol.

With this mechanism, the simulator's line of sight can be changed by the horizontal rotation of the avatar's body and its head's pitch rotation. The clock time in the simulator, the compass point names, and the azimuth altitude of the line of sight are displayed on the PC screen.

To see the sun in the simulator, a learner simply rotates the globe and reorients the avatar's body and its head toward the light. With this configuration, learners are expected to naturally relate the earth's rotation, the avatar's posture, the relative position of the earth and the sun, and the sun's diurnal motion.

3.2 Remaining Issues

Following the DBR process, we have been invesitigating the effect of tangible globe system on learning activities. Especially, based on the Price's framework [9], we raised a few issues to be solved [6].

The first issue is about *location* of information. Since the time and orientation are shown on the display, the learners tended to focus only on the display and they did not pay atention to the positional relationship of the globe, avatar, and the sun.

The second issue is about *manipulation* of tangible objects. To observe the sunrise and the sun's culmination, the learners had to adjust the rotation of the globe and the head of the avatar so that the sun could be seen in the center of the PC screen. However, the learner seemed to manipulate the these objects randomely without thininking of the meaning of manipulation.

To alleviate these issues while satisfying the requirements for the embodied design, we decided to apply following two improvements to the system:

– Improve the avatar so that the learners can understand that the avatar is their surrogate and they have to pay attention to its line of sight.
– Imporve the study procedure so that the learners can manipulate the avatar while contemplating the meaning of the manipulation.

3.3 Improvement of the Avatar

As the first improvement, we changed the avatar from chicken like appearance to a person like appearance, and made it have a long nose like Pinocchio to make it easy to recognize the gaze direction.

As a second improvement, we embeded motors in the avatar so that its neck can tilt back and forth for 90 degrees, and the whole body rotates in the pan direction infinitely. Below the avatar, we attached a orientation board which denotes eight azimuth orientations so that learners can easily recognize the avatar's current orientation. The avatar has two control modes, a manual operation mode in which the avatar is operated by hand, and a body motion synchronization mode in which the avatar moves synchronously with the learner's body motion (Figure 2). We used a tablet PC (Microsoft Surface Pro 3) for body motion synchronization mode.

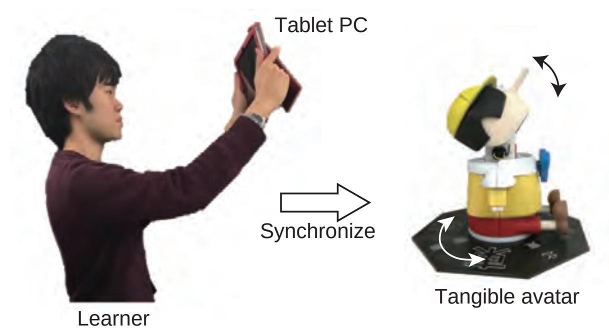

Fig. 2. Body motion synchronization mode of the avatar

4 Experiment

We conducted an experiment at a junior high school in Tsukuba, Japan. Eight second grade male students (learners) participated in the experiment.

4.1 Study Procedure Design

We applied pretest and posttest to examine the knowledge level of the participants. In the pretest, we asked questions on the orbit of the sun's diurnal motion, the direction of the rotation of the earth, directions of east, west, north, and south on the globe, the sun's trajectory at the sunrise and sunset in Japan. As for the posttest, in addition to the same questions as the pretest, questions about the orbits of the diurnal movement in Australia was asked.

After the pretest, we instructed how to use tangible glove system. Then, the learners became a group of two and worked on the two tasks written on the worksheet using the system. The tasks asked the learners time, elevation angles, and directions at the sunrise, mid-day, and sunset in June 21 (summer solstice) both in Japan and in Australia. The Learners attached the avatar to Japan or to Australia first. Then by taking the relative position of the avatar with the sun into consideration, they rotated the globe so that the avatar was brought to sunrise, sunset, and midpoint positions. Then, while manipulating the avatar, they observed the movement of the sun on the tablet PC screen and answered the questions in the worksheet.

We conducted the fist experiment in the morning with four learners and second experiment in the evening with other four learners. Since the study procedure for the first experiment was similar to our past experiments, we still saw the similar issues that was observed previously (see 3.2). Thus, following the DBR approach, we redesigned our study procedure for the second experiment.

In the second experiment, the learners performed the following procedure for Japan and Australia when observing sunrise, culmination, and sunset in manual operation mode.

1. Laied the tablet PC's screen down so that the screen is not visible.
2. Manipulated the avatar and the globe to the appropriate positions to observe sunrise, culmination, and sunset respectively.
3. After the learners determined that they adjusted the avatar to the correct position and orientation, they turned the tablet PC over to see that the simulator showed the expected time and the sun was at the expected position (in case of the sunrise, for example, the learners made sure that the sun was near the east horizon).
4. Brought the sun at the desired position while finely adjusting the globe and the avatar, and recorded the time and orientation on the worksheet.

Next, the learners performed the following procedure for each Japan and Australia. During the following two steps, the learner who manipulated the tablet PC stood on a orientation indicator mat (Figure **??**) so that the learner can always be aware where he was oriented to.

1. First, the system was set to manual operation mode, let the learners hold a tablet PC with blank display, and move the tablet PC to simulate the sun's diurnal motion both in Japan and in Australia.
2. Start the simulator on the tablet PC, set the body motion synchronize mode, let the learners observe sunrise, sunset, and culmination, and record the time and orientation in the worksheet.

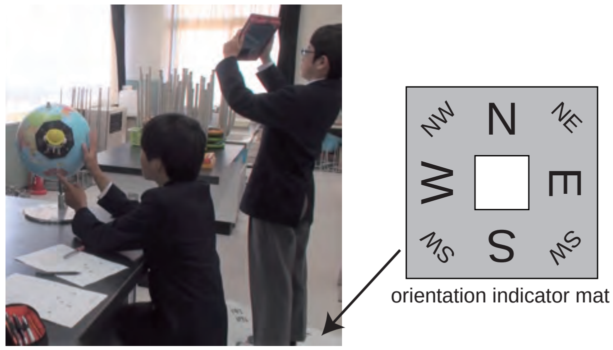

Fig. 3. Manipulating the tablet PC on the orientation indicator mat

5 Results

The correct answer rate of the pretest was 50% on average and the correct answer rate of the posttest is 82% on average. We observed that learners were making projections while thinking about relationship between the avatar, the globe, and the sun. Figure 4 is a scene that the learners were speculating the posture of the globe and avatar at the time of culmination in Australia. After P1 and P2 manipulated the avatar together, they confirmed that the avatar's gaze direction was heading toward the sun by seeing it from the avatar's face position.

Fig. 4. Learners focusing on the relation between the avatar and the sun

Figure 5 is a scene where another group was trying to observe the culmination in Australia. First of all L3 thought that avatar should face to the south to observe the sun at noon, so while saying ”south”, he manipulated the avatar to face the sun. At this time, L4 was also paying attention to the avatar, but by seeing the orientation board at the avatar’s feet, they simultaneously noticed that the avatar was facing to the north. Then, as L4 pointed at the orientation board, asked L3 ”North?” (Figure 5 (a)). After that, L4 rotated the avatar to the south and tried to lift the neck up to make it look to the sun. However, since the avatar’s neck stopped at its 90 degrees, the avatar’s line of sight did not reach the sun (Figure 5 (b)). As a result, it was impossible to make the avatar see the sun in Australia if the avatar faced the south, which made both L3 and L4 understand that the sun culminates to the north in Australia.

From these examples, by employing a stage where participants predict only from the postures of avatar and the globe without looking at the tablet PC, both of the groups could focus on the avatar and the globe. Such focus seemed to led them to be conscious of the relative positions of the globe, the avatar, and the sun. Furthermore, by applying various manipulations to them, the learners seemed to better understand the phenomena.

Fig. 5. Discussing about culmination in Australia

Figure 6 is the scene when L2 was working on the posttest and trying to remember the movement of the sun at the time of sunrise and sunset. By swingin his arms from right to left, L2 seemed to reproduce the action that he did during the body motion synchronization mode. Since the learners had an experience to move the tablet PC to follow the sun’s diurnal motion, it is possible that such an operation was internalized.

6 Discussion

Through our previous experiments [6] as well as the first experiment in this study, we obtaned an implication that ”**In the case where an appropriate**

Fig. 6. Simulating the motion

learning procedure is not provided, the intuitive operability of the tangible user interface may rather impede the learner's thinking."

On the other hand, in our second experiment, we first made the learners predict the result without seeing the display of the tablet PC. This process seemed to made them contemplate how the avatar's posture should be in relation to the positions of the globe and the sun. Furthermore, as an example of the Figure 5 shows, when the learners found that the result was different from their predictions, they tried to understanding the phenomena while manipulating the avatar. The example of Figure 6 shows the possibility that the learner internalized the manipulation of the tablet PC. Therefore, the study procedure in our experiment seemed to support embodied design concept to some extent. From these discussions, we propose an implication that "**it is effective for the learners to restrict the information to be provided first, then, let them perform trial and error as they manipulate objects, and let them predict the result**."

7 Result

In this paper, by analyzing the experiment of astronomy education using the tangible globe system, we aimed to obtain implications about the learning procedure that enables to use the tangible learning environment effectively. We conducted observational study and analyzed the results based on the idea of embodied design. Based on the analysis, we proposed two implications, 1) if an appropriate learning procedure is not provided, the intuitive operability of the tangible user interface may rather hinder the learner's thinking, and 2) it may be effective to restrict the information to be offered to the learners first, let them try trial and error while manipulating artifacts, and let them predict the result. In the future, further experiments should be conducted with various learning procedures. It is also necessary to clarify what kind of scaffolding is effecitve for embodied design.

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