Tangible Earth: Tangible Learning Environment for Astronomy Education

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ABSTRACT
To support astronomy education, we developed a tangible learning environment called the tangible earth system. To clarify its problems, we defined an assessment framework from the aspects of curriculum guidelines, design guidelines of tangible learning environments, and epistemology of agency. Based on the analysis of our small-scale user study, we identified problems of the system in terms of location, dynamics, and correspondence parameters.

Author Keywords
Astronomy education; educational technology; tangible bits.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

INTRODUCTION
Among astronomy curricula, concepts related to earth-sun relationships are difficult since students need to understand how the spatial and temporal relationships between the sun and earth cause daily and seasonal variations in various phenomena [5, 8], including the sun's diurnal motion. Even some preservice elementary school teachers fail to fully understand these relationships [1].

One promising approach that helps students effectively grasp basic astronomy concepts is using a globe [1, 5] and a doll-like figure on it [9]. Indeed, many studies have applied a tangible user interface (TUI) for educational purposes [4, 10] and astronomy is one major target for educational technology. TUI's physicality and intuitive user interface seem to be effective in learning scientific phenomena.

By taking these approaches, we developed a tangible learning environment (TLE) called *tangible earth system* to support the learning of earth-sun relationships (Figure 1) and have been applying it in experimental classes for junior high students. Although most of the students and teachers were enthusiastic about the system, we also saw instances where it was not effectively embraced. Therefore, we conducted a small-scale observational study to understand the pros and cons of our approach.

In the rest of this paper we first explain our assessment framework. Next we introduce our tangible learning environment and use it to describe an observational study and its results. Finally, we discuss design implications of TLE for astronomy education.

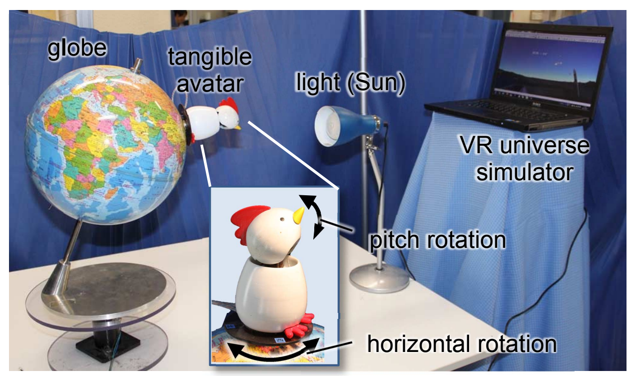

Figure 1. Tangible earth system.

ASSESSMENT FRAMEWORK

Curriculum Guidelines
The earth-sun relationship is part of the science curriculum for junior high schools in Japan. According to a report on curriculum guidelines for science education from the Ministry of Education [3], the purpose of astronomy education is to teach students how to understand the earth's movement through observations of celestial bodies and the characteristics of the sun and the planets with figures and physical models. Through such activities, the curriculum enables students to form spatial and temporal concepts so that they can develop skill in perceiving the positions and motions of astronomical bodies as relative concepts. Based

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on the government report, we derived the following specific curriculum goals to enable students to form temporal and spatial concepts:

- Temporal concept: teaches students to relate the earth's rotation to the recorded observations made by students of the sun's diurnal motion.
- Spatial concept: teaches students to relate the sun's celestial positions to the positions and orientations of an observer on earth.

Our analysis focuses on our system's influence on learning temporal and spatial concepts.

Design Guidelines for Tangible Learning Environments

TLEs are one of the trends in educational technology research, and many systems have been proposed [4, 5, 10]. Researchers have also started to discuss design frameworks [2, 6]. Particularly Price's framework highlights the effect of the external representations of the TLE on learning. As the aim of the curriculum for astronomy is to enable students to form temporal and spatial concepts through *observation* of various phenomena, appropriateness of our system's external representations to be observed is our main concern. Thus, in this study, we employ Price's framework for the analysis of the tangible earth system.

Price proposed a "conceptual framework for systematically investigating how different ways of linking digital information with physical artefacts influence interaction and cognition, to gain a clearer understanding of their role for learning [6]." Framework parameters included location, dynamics, correspondence, and modality. We will briefly explain all of them.

Location parameters refer to how physical artifacts and digital representations are located to each other. They are *discrete* if the tangible input device and the digital output device are located separately; they are *co-located* if the input and output are contiguous; and they are *embedded* if the digital output is displayed within a tangible object.

Dynamics parameters refer to the information association between artifact and representation. More specifically, they discuss whether "digital effects can occur contiguously with intentional action, generating an expected effect, or they can be inadvertently triggered according to pre-determined configurations, causing an unexpected effect [6]."

Correspondence parameters "refer to the degree to which the physical properties of the objects are closely mapped to the learning concepts." They are *symbolic* if the objects act as common signifiers. For example, blocks are symbolic because they can be used to represent various entities. They are *literal* if the objects' "physical properties are closely mapped to the metaphor of the domain it is representing [6]."

Modality parameters refers to how audio and tactile modes affect learning. Since our tangible earth system does not utilize these modalities, we do not consider this parameter in this study.

Based on the parameters, we analyzed the influence of our system on learning temporal and spatial concepts from the aspects of *location*, *dynamics*, and *correspondence* parameters.

Epistemology of Agency

As an effective way to assist learners to understand scientific phenomena, Saeki proposed the conceptual theory of "epistemology of agency." He discussed the effectiveness of a learner's agents in understanding various scientific phenomena [7]. According to his theory, it becomes much easier for a learner to understand scientific phenomena if he/she imagines placing his/her agents (or surrogates) in various places of a scientific model and posits what they would observe from their perspectives. Based on this theory, we assumed that the doll-like figure on the globe would play a role of the learner's agent and it should be effective in learning earth-sun relationships.

In our analysis, we are interested in if learners actually perceive the doll-like figure as their surrogate.

SYSTEM OVERVIEW

Our TLE, called the tangible earth 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[1] to show the diurnal motion of the sun in the celestial sphere (ground-level view).

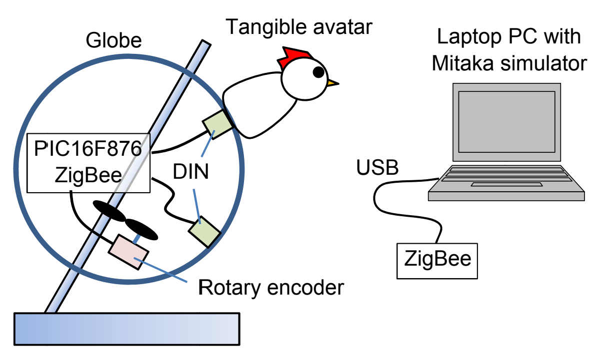


Figure 2. Mechanism of tangible earth system.

Figure 2 shows mechanism of the system. 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

[1] http://4d2u.nao.ac.jp/html/program/mitaka/index_E.html

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.

OBSERVATIONAL STUDY

We conducted an observational study with junior high students who interacted with the tangible earth. During the activity, they completed a worksheet that had questions. The activity was videotaped for subsequent analysis.

Participants and Apparatus

Seven Japanese 8th graders were participated in our study. They were divided into three groups: two males, three females, and two females. Each group was given a tangible earth system and allowed to freely interact with it during the activity. Note that to breed a congenial atmosphere, we accepted all the students who wished to participate in the activity and did not strictly control the gender balance and the number of students in a group.

Before the subjects started to work on their worksheets, they were given a short lecture to recall such basic knowledge about astronomy as the earth's rotation direction, compass directions, revolutions, and axial tilt. They also learned how to manipulate the system.

For simplicity, we did not use the rotating table, and the simulator's date was fixed around June 22nd, which is the summer solstice.

Procedure and Data Analysis

The worksheet consisted of seven questions. For instance, participants were asked 1) to illustrate the earth's rotational direction, 2) to answer four azimuth on the globe, 3) 4) to find the compass directions of the sunset and the sunrise, 5) to find the sun's culmination altitude for Japan, 6) to draw diurnal motion on a celestial chart, and 7) to do answer the same questions for Australia.. During the exercise, the experimenters occasionally asked the students to explain their answers, e.g., concerning why the compass directions of the sun's culmination of Japan and Australia are opposite.

We videotaped the student activities and drew on the conversation analysis and recent studies of multi-modal interaction. In this respect, participant learning interactions were classified into temporal and spatial concepts. Then the interactions for each concept were further classified into location, dynamics, and correspondence.

RESULTS

Since all three groups took about an hour to finish their worksheets and answer our questions, we gathered about three hours of videotaped data.

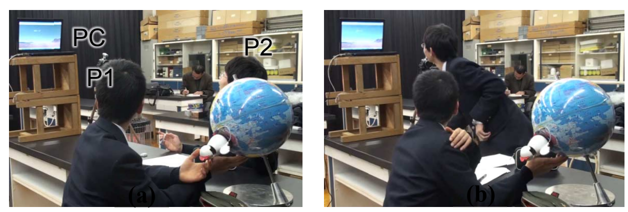
Temporal Concept

Learning temporal concepts is mostly related to the globe's rotational manipulation, particularly when the participants changed the points in time to sunrise, noon, and sunset. In general, these interactions seemed quite intuitive for all of them.

When the participants sought the three points in time, they instantly confidently started to rotate the globe. In many cases, they did not even look at the globe while they were controlling the time, causing other problems described later. This shows that they had no problem with the *location* parameter. Furthermore, the interface is clearly appropriate in terms of *dynamics* and *correspondence* parameters because the participants easily related the sun's diurnal motion to the earth's rotation.

Spatial Concept

However, we observed various problems for supporting spatial concept learning.



(a) (b)

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P2: The Sun is going down.
P1:                          Okay.
                           *a

P2: I can't see the compass point. Let it look down.

P2: Something is written.                     West-northwest.
P1:                            West-northwest.
                           *b

P1: (Sunset) Direction is the same (as Japan).
P2:

P2: I wonder why. I wonder why. It is intriguing.
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Figure 3. Participants observing sunset. "*" indicates the time when corresponding image is captured.

Location

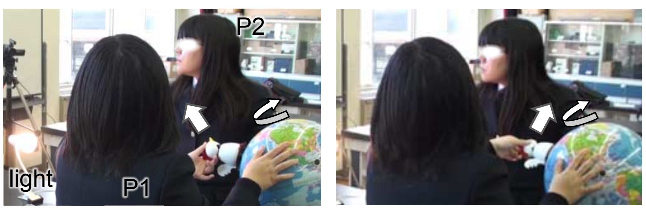
In this experiment, since most of the worksheet answers (compass point names and the sun's azimuth altitude) could be found on the PC screen, the participants tended to concentrate on their PC screen.

In Figure 3, participants are trying to determine the compass point for the sunset in Australia. P1 is manipulating the avatar attached to Australia. Then, they find that the Sun goes down to west-northwest. P1 then is aware that compass points of sunset are the same for Japan and Australia. Although P2 wonders why they are the same, he cannot find the reason.

To understand why the compass points of the sunset is the same for Japan and Australia, participants must look at the avatar's orientation on the globe. However, during this activity, they rarely looked at the avatar and instead mostly focused on their PC.

Dynamics

In Figure 4, P1 is trying to find the sunrise by manipulating the avatar and the globe. To do so, she first tries to capture the sun in the field of view of the PC screen. While P1 is rotating the globe, both P1 and P2 keep looking at the PC screen. When the avatar is located around the noon position, P1 orients the avatar to the north and makes it look up almost straight up. Then the sun enters the PC screen's field of view and she says "Oh, I found the sun" (Figure 4a). She orients the avatar's body to the west, horizontally tilts its head down, and rotates the globe clockwise again (Figure 4b). Since the avatar's head is now orienting toward a quite different direction from the light, the sun in the PC screen disappears. Failing to understand the reasons for the disappearance, P1 says, "The sun sun sun . . it's gone!"



(a) (b)

Figure 4. Participants trying to keep the sun in the PC screen while rotating the globe.

For the sun to be seen in the PC screen, P1 had to keep the avatar's head orientation toward the light. However, her intentional manipulation of the avatar failed to cause the effect that she intended. We have seen other examples where participants manipulated the interface without being conscious of its meaning.

Considering the fact that the participants manipulated the avatars back and forth like manipulating a game controller, facile manipulation of the tangible interface may be one factor that prevented the participants from conceptually understanding the intentional action of manipulation.

Correspondence

One of the experimenters asked a group of two boys why the compass directions of the sun's culmination were different between Japan and Australia. One of the participants gave the following answer:

Because the sun is at the height of the equator (Figure 5a-i), if the avatar is above the equator, the sun is seen in the south (Figure 5a-ii). If the avatar is below the equator, it is seen in the north (Figure 5a-iii).

Although this answer is correct within the given physical properties of the TLE, it is wrong in the real world. The problem which led them to a misunderstanding was that the light was too small, and the distance to the globe was too close compared to the actual relationship between the sun and the earth. In reality, since the sun is quite far from the earth, its rays come almost in parallel (Figure 5b).

(a) (b)

Figure 5. Misunderstanding caused by misleading representation

DISCUSSION

The analysis in this paper revealed that our system has problems in its learning spatial concept. This section proposes design some design implications of TELs for astronomy education.

The *location* parameter of astronomy education tends to be discrete because it must show multiple images of different points of views, typically a ground-level view of the celestial sphere and a birds-eye-view of the solar system. Therefore, the auxiliary information's location must be carefully considered so that it draws student's attention to appropriate objects. Careless choices may lead to disregarding important views, as seen in Figure 2. In our case, the compass point names and the azimuth altitudes of the sun should have been co-located/embedded with avatars.

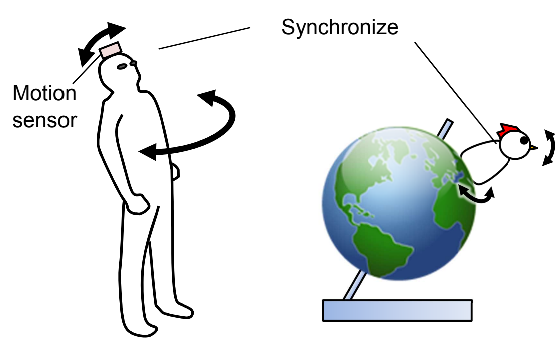


Figure 6. Synchronizing motions of a learner and the tangible avatar

As for the *dynamics* parameter, our example (Figure 4) indicates that students tend to manipulate a TUI like an unfamiliar game controller, without being conscious of the properties it represents. One way to alleviate this problem is to make a learner deem that the avatar is their surrogate. For example, we are planning to synchronize the avatar's motion with the learner's head motion. As shown in Figure 6, the learner's motion can be detected by attaching a motion sensor to his/her head. We also need to embed motors into the avatar to control head and body movement. We will not synchronize the motion of the avatar and the learner all the time while he/she is learning. Instead, we will temporarily synchronize them at the beginning of a learning session and let the learner observe the synchronized motion. With this experience, we are expecting that the learner can have a sense that the avatar is his/her surrogate.

The *correspondence* parameter can be a problem not only for astronomy contents but also for various scientific contents because many physical models that represent scientific phenomena are inevitably symbolic to some extent. We also need to keep in mind that there is a trade-off between *being literal* and other factors. In our case, for example, we could have placed the light further away from the globe than the current setup, i.e., behind the PC. This setup might have been better for students to deliberate the issues of sun's culmination. Conversely, the setup might have diminished the participants' awareness to the earth-sun relationship which might not be preferable for other activities.

One solution is to make the system flexible in terms of reconfigurability and changeability of tangible objects. Then, during an activity, a teacher chooses the suitable configuration/objects corresponding to the perspectives students need to learn. In that case, appropriate explanation for the change should be provided to the students as well.

CONCLUSION
We developed a tangible earth system to support astronomy education. Based on curriculum and general design guidelines for tangible learning environments, we discussed a framework to assess a tangible learning system for astronomy education. The observational study with junior high school children revealed problems of the system in terms of location, dynamics and correspondence parameters. Our next step is to apply our ideas to improve our tangible earth system and conduct a large-scale user study.

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REFERENCES

1. Atwood, R. K. and Atwood V. A. Effects of Instruction on Preservice Elementary Teachers' Conceptions of the Causes of Night and Day and the Seasons. *Journal of Science Teacher Education* 8, 1 (1997), 1-13.
2. Marshall, P. Do tangible interfaces enhance learning?, In *Proc. TEI 2007*, ACM Press (2007), 163-170.
3. Ministry of Education, Culture, Sports, Science and Technology-Japan. http://www.mext.go.jp/component/a_menu/education/micro_detail/__icsFiles/afieldfile/2011/04/11/1298356_5.pdf
4. Moher, T., Hussain, S., Halter, T., and Kilb, D. RoomQuake: Embedding dynamic phenomena within the physical space of an elementary school classroom. In *Proc. CHI 2005,* ACM Press (2005), 1655-1668.
5. Morita, Y. and Setozaki, N. Practical Evaluation of Tangible Learning System: Lunar Phase Class Case Study. In *Proc. of SITE 2012*, (2012), 3718-3722.
6. Price, S. A representation approach to conceptualizing tangible learning environments. In *Proc. of TEI 2008*, ACM Press (2008), 151-157.
7. Saeki, Y. Cognition and Learning by Imaging (Ime-jika niyoru chisiki to gakushu) (in Japanese), Toyokan Publishing, Tokyo (1978).
8. Shelton, B. and Hedley, N. Using Augmented Reality for Teaching Earth-Sun Relationships to Undergraduate Geography Students, In *Proc. ART02*, IEEE (2002), 8 pages.
9. Vosniadou, S., Skopeliti, I., and Ikospentaki, K. Modes of knowing and ways of reasoning in elementary astronomy. *Cognitive Development* 19, 2 (2004), 203-222.
10. Zuckerman, O., Arida, S. and Resnick, M. Extending tangible interfaces for education: digital Montessori inspired manipulatives. In *Proc. of CHI 2005*, ACM Press (2005), 859-868.