Vegetation Succession Learning Support System for Virtual Forestry Management - Toward the Maintenance and Conservation of the Natural Environment

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Abstract

In recent years, various environmental problems such as air pollution, global warming, the attenuation of biodiversity, and deforestation are becoming global issues. To solve them, children, who are responsible for the future of humanity, must be interested in these problems and learn about them. Experience is a key part of understanding, but these environmental problems are difficult to experience. In particular, it is difficult for children to experience vegetation successions, which are deeply affected by factors such as biodiversity and forest destruction and occur over a long time scale. Therefore, we developed a game about managing forests to simulate vegetation successions so that they can be taught to children. Furthermore, to evaluate the game, we performed a user study in which 16 elementary school students participated. The results show that the children could experience and learn about vegetation succession by playing this game. The results also suggest that this game helps children become interested in biodiversity and forest destruction.

Keywords

Environmental Education, Game, Biological Diversity, Experience

1 Introduction

In recent years, various environmental problems such as air pollution, global warming, attenuation of biodiversity, and deforestation have become serious globally. To solve these problems, people need to develop a deep understanding of them. In particular, young learners, who are responsible for the future, must learn about environmental problems. Under such circumstances, it is important for these learners to understand and experience changes in the natural environment in a realistic way. However, learning from textbooks and teachers does not provide real-world experience.

In Japan, the term *satoyama* refers to a forest zone that occurs between natural and rural areas. The Japanese word *sato* means village, and *yama* means mountain. Therefore, a satoyama is considered to be a good ecosystem in which learners can experience vegetation succession in a natural area and can acquire practical knowledge of environmental problems. Concepts such as biological diversity and forest destruction in satoyama are related to a complicated mechanism related to the actual vegetation succession. However, the practical knowledge relating to these concepts cannot be obtained simply from textbooks and teachers. Furthermore, because actual vegetation successions occur over a long time scale, from several decades to several centuries, even if learners did field work in satoyama, they would be unable to experience the changes in vegetation. Therefore, it is difficult to understand and experience vegetation succession in a realistic way. One way to solve this problem is to develop a game-type learning support tool to enable learners to experience vegetation succession without being hampered by the passage of time.

The use of games for learning purposes has attracted considerable attention (Facer, et al., 2004, Squire and Klopfer, 2007). These early studies revealed that learners can virtually experience microscopic and macroscopic worlds that are different from the real world by playing games. However, our focus is to teach environmental problems through the vegetation succession in satoyama. The authors developed a game called “Human Sugoroku” that uses the preservation of satoyama as a tool to enable players to learn about familiar environmental problems. The original sugoroku is a type of board game. The game we developed introduces various environmental disturbance factors such as logging, landslides, and precipitation. The value of plants and the need to manage their growth in the face of environmental disturbance factors are expressed in the sugoroku format. In addition, we conducted research on animated learning materials that enable learners to visually grasp the vegetation succession of satoyama (Deguchi, et al., 2010, Deguchi, et al., 2011). The results revealed that the game format enhances players’ motivation to learn about vegetation succession, promotes their understanding of the complex mechanism underlying vegetation succession, and improves their ability to solve environmental problems (Adachi, et al., 2013, Nakayama, et al., 2014, Yoshida, et al., 2015). However, the world of the game was limited to a specific area. Large-scale ultrasonic sensors were used in this game, and players worked on the grid cells in the virtual world that represented indicator plants, but this merely realized a limited sense of immersion. The following four observations were made:

- This game could not express the competitive relationship between various kinds of plants and environmental disturbance factors.
- Because of the lack of large facilities and game portability, it would be difficult to use this game under many circumstances.
- Because the embodiment was limited, it was impossible for the learner to fully experience immersion in the virtual world.
- The game content was not adapted to the learner's intelligence.

This prompted us to set the following goals for our current research in order to deepen learners’ understanding of vegetation succession and to improve their ability to solve problems:

- to develop a wide range of content that includes examples of major vegetation succession throughout Japan;
- to use mobile devices to develop games with high portability;
- to adapt the contents of the game to the learner's intelligence.

As the first step toward achieving these goals, this paper presents details of the current implementation of the game and the experiments conducted on it.

2 Vegetation Succession Learning Support System

2.1 Overview

The name of the game developed for this study is the "Satoyama Management Game." This implementation of the game enables a learner to experience the management of vegetation succession in satoyama within a virtual world. Through this experience, players experience the complicated mechanisms of satoyama with the aim of improving their ability to solve environmental problems in satoyama. Figure 1 shows the user interface of the game. It simulates a satoyama region in that the ten kinds of plants arranged at the top of the screen form the vegetation. The number shown to the right of each plant is the number of plants in the vegetation. From the left, the following plants are shown.

- Early-stage species: *Rubus microphyllus* and *Mallotus japonicas*
- Middle-stage species: *Pinus densiflora*, *Quercus serrata*, *Rhododendron reticulatum*, *Vaccinium oldhamii*, and *Abelia spathulata*
- Late-stage species: *Castanopsis spp.*, *Quercus glauca*, and *Eurya japonica*

The game begins in a poor state in which many late-stage species have become vegetated. Learners have to improve forests starting from an adverse environment (environments with poor biodiversity) and moving to an ideal state (an environment rich in biodiversity). In this implementation of satoyama, in addition to the above ten plants, pine longicorn beetles and deer occur. The influence on each plant

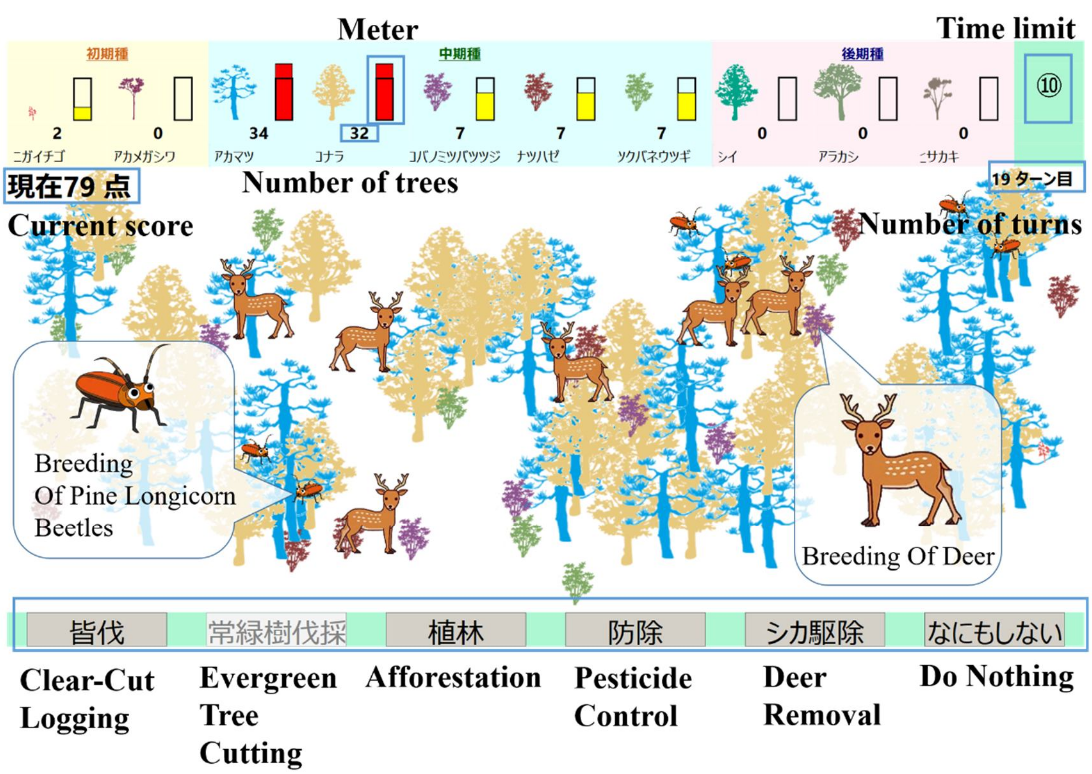

Figure 1: Screenshot of the Satoyama Management Game.

due to the occurrence of these competitors depends on the characteristics of plants. For example, pine longicorn feeds on *P. densiflora* and deer prefer small seedlings. In addition, the competition among plants also affects the extent to which the number of plants increases and decreases. As large plants grow, they prevent sunlight from reaching small plants; thus, the small plants cannot grow. Apart from this, large plants are easy to grow.

These factors require the player to select the management method within a predetermined time taking into consideration the feeding damage caused by pine longicorn and deer and the competition among the plants. The number shown in the upper-right corner of the screen is a timer. The player must select the management method within 15 s per turn. They then repeat that management method for 20 turns. The number of turns at that time is indicated beneath the countdown. The state of the vegetation is displayed in the center of the screen. Selection buttons for the following management methods are arranged at the bottom of the screen:

- Clear-cut logging
- Evergreen tree cutting
- Afforestation
- Pest control
- Deer removal
- Do nothing

The vegetation of satoyama varies according to the management method selected by the player. During each of the 20 turns, 15 years pass; thus, the player experiences satoyama management for 300 years.

The following functions are provided to assist learner management: First, the current forest state is displayed as a score (the score of the ideal state is 100 points). Evergreen trees are constantly increasing. As a result, short trees cannot be planted and the forests will have lower biodiversity if the player does not manage the forest well. A bad example of management would be to not cut down evergreen trees appropriately and leave deer and insects. As a result, the score finally becomes 0, as shown in Figure 2. Second, to achieve the ideal number of each plant species, the current number of each species relative to the ideal number is indicated by a meter. Because the ideal number is different for each species, there are meters for each one. When the meter is full, it implies that the ideal number has been attained; when it exceeds the limit, this indicates that there are more trees of that species than necessary. Using these functions, players can learn how to manage forests.

2.2 System Flow

Figure 3 shows the system flow. First, at the start of the turn (at 15 s remaining), the change in the number of plants determined during the previous turn and the existence or extermination of pine longicorn and deer are shown. Then, for the duration of the next turn (from 14 s to 1 s remaining), the change in the number of plants is determined. The following three factors of vegetation succession are

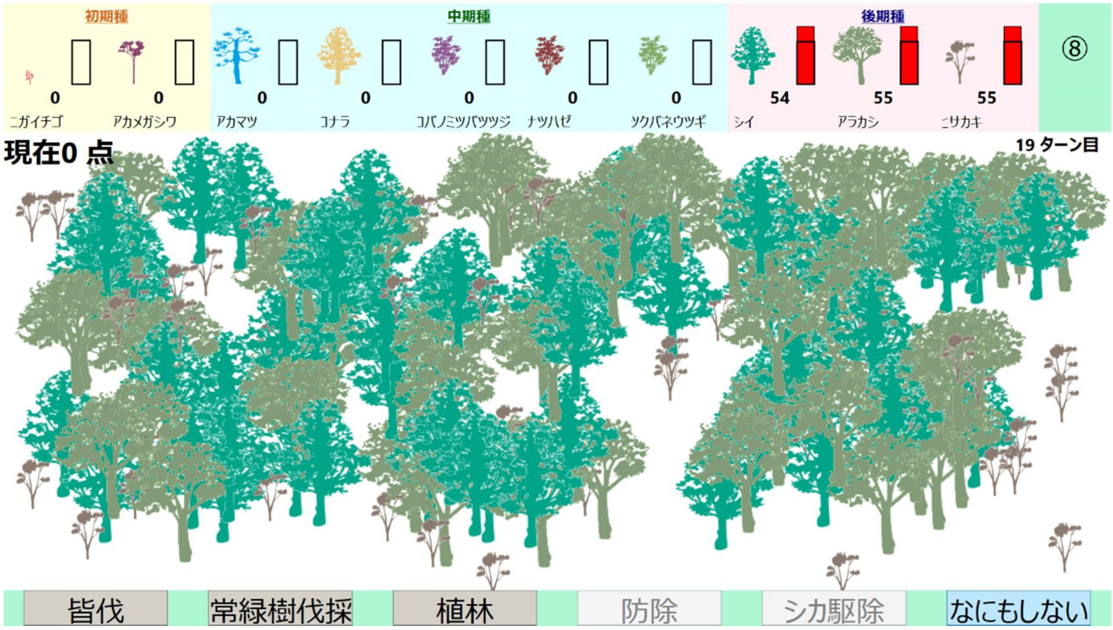

Figure 2: Evergreen tree only state (0 points).

used to determine the change in the number of plants:

- Plant-to-plant dominance
- Damage by pine longicorn and deer
- Influence of management by people

To reproduce these effects, we interviewed professors who are specialists in phytosociology at Kobe University and created parameters for the factors influencing vegetation succession. The change in the number of plants over a turn is displayed as follows to clarify the change in vegetation succession at the end of the turn (at 0 s remaining).

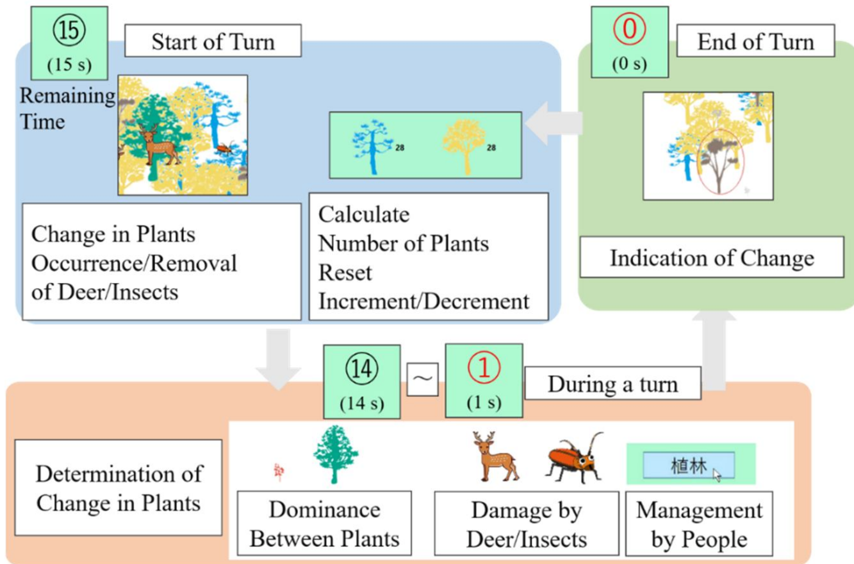

Figure 3: System flow during one turn.

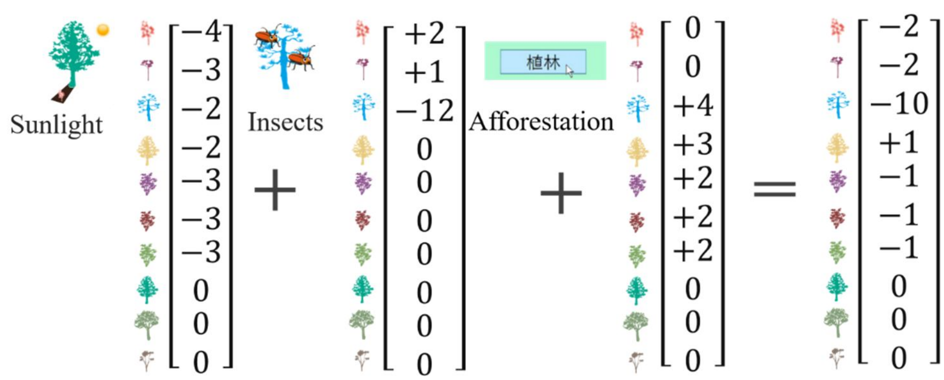

Figure 4: Example of calculating the change in plant numbers.

The plants that have increased in number are marked with red circles, and those that have reduced in number are shown in gray. Then, the game proceeds to the next turn.

Figure 4 shows one example in which the change in the number of plants is determined. As a consequence of the inter-plant dominance relationship, the growth of a tall plant will cause a shorter plant to be shielded from sunlight and die. In addition, as a result of the presence of pine longicorn and deer, plants that can be eaten by one of these pests will decrease in number. Moreover, species numbers will change as a consequence of human management; for example, planting plants that promote afforestation will increase the occurrence of that plant. By combining the values of these parameter, we determine the number and type of plants that change during vegetation succession.

3 Experiment

We evaluated the Satoyama Management Game through a user study in which 16 six-grade students (aged 11–12 years, 6 boys, 10 girls) at an Elementary School Attached to Kobe University participated.

Each participant played the Satoyama Management Game six times. We let participants play six times so that they could try various management methods. The experiment was scheduled such that a preliminary survey was conducted during the lunch break. Then, the participants played the game four times. Subsequently, the game was played twice after school and a post-survey was conducted. The questionnaires used in the survey and the post-survey were identical. We also conducted an interview. Figure 5 shows the experimental environment.

Figure 5: Experiment environment.

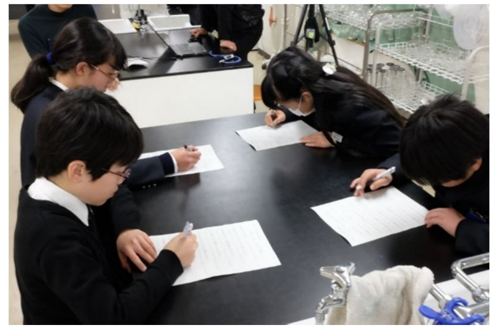

Figure 6: Children answering the questionnaire.

3.1.1 Evaluation by Questionnaire

We asked participants to answer two questionnaires to determine i) their impression of the game, ii) self-understanding about their knowledge of satoyama, and iii) their knowledge of satoyama management. Figure 6 shows the children answering the questionnaire.

The first aim of the questionnaires was to evaluate the interest and enjoyment of the Satoyama Management Game and its interface. Ten questions in the post-survey were used for evaluation. The second aim of the questionnaires was to ascertain how much participants thought they knew about satoyama, and whether this changed after the game experience. Four questions in the preliminary survey and post-survey were employed. The third aim of the questionnaires was to ascertain how much participants' knowledge on satoyama management changed before and after the game experience. Two questions on the preliminary survey and a post-survey were used to evaluate this aim.

For each statement in the questionnaires, the participants rated their feelings according to a 7-point Likert scale, choosing from “Strongly Agree,” “Agree,” “Slightly Agree,” “Neither Agree nor Disagree,” “Slightly Disagree,” “Disagree,” and “Strongly Disagree.”

3.1.2 Result

To analyze the results for the students' impression of the game, we sorted the responses into positive (Strongly Agree, Agree, Somewhat Agree), and neutral/negative (Neither Agree nor Disagree, Somewhat Disagree, Disagree, Strongly Disagree). We then analyzed the number of positive and neutral/negative responses using Fisher's exact test, with a 1×2 contingency table. Table 1 summarizes the questionnaire results, which show that positive responses to all ten statements outnumbered neutral/negative responses. A significant bias was observed among the number of responses.

Statement	7	6	5	4	3	2	1
The Satoyama Management Game was fun. **	15	1	0	0	0	0	0
In the Satoyama Management Game, I focused on satoyama management. **	12	3	0	1	0	0	0
I was pleased when the score went up. **	15	1	0	0	0	0	0
I was frustrated when the score dropped. **	9	5	2	0	0	0	0
It was a pleasure to predict the changes caused by actions such as clear cutting, evergreen tree cutting, afforestation, control, deer removal, and so forth.**	12	2	1	1	0	0	0
By looking at the screen of the Satoyama Management Game, it was easy to understand the numbers of each type of tree in the satoyama. **	5	6	3	2	0	0	0
Looking at the screen of the Satoyama Management Game, it was easy to understand the occurrence of the deer in the satoyama. **	11	4	1	0	0	0	0
By looking at the screen of Satoyama Management Game, it was easy to understand the presence of insects in the satoyama. **	10	5	1	0	0	0	0
Watching the screen of the Satoyama Management Game, it was easy to understand the state of the satoyama. **	11	3	1	1	0	0	0
The Satoyama Management Game was easy to operate. **	15	1	0	0	0	0	0
N = 16, **P <.01 7: Strongly Agree, 6: Agree, 5: Slightly Agree, 4: Neither Agree nor Disagree, 3: Slightly Disagree, 2: Disagree, 1: Strongly Disagree							

Table 1: Evaluation Results: Impression of the game

To evaluate the results of the four questions pertaining to the self-understanding of knowledge about satoyama, a sign test was used on the 7-point Likert scale responses of the preliminary survey and post-survey to analyze the number of positive and neutral /negative reactions. Table 2 summarizes the responses of the questionnaire. The results of the sign test show significantly different responses for all four questions.

Statements		7	6	5	4	3	2	1
I understand the problem of maintaining satoyama. **	Before	0	2	6	3	1	3	1
	After	4	5	6	0	1	0	0
I know the methods necessary to maintain satoyama. **	Before	0	1	2	3	3	2	5
	After	6	4	4	1	0	1	0
I know the law of vegetation succession necessary to maintain satoyama. **	Before	0	0	2	2	1	1	10
	After	1	4	3	2	4	0	2
I know what satoyama maintenance problems will happen in the future.	Before	0	0	1	5	5	1	4
	After	3	5	5	2	1	0	0
	N = 16, 7: Strongly Agree, 6: Agree, 5: Somewhat Agree, 4: Neither Agree nor Disagree, 3: Somewhat Disagree, 2: Disagree, 1: Strongly Disagree, **p <.01							

Table 2: Evaluation Results: Self-understanding of knowledge about satoyama

Finally, we evaluated the responses of the two questions pertaining to satoyama management. Again, the sign test conducted between the responses of the preliminary survey and post-survey showed a significant difference in both questions.

Statements		7	6	5	4	3	2	1
In order to maintain satoyama, evergreen trees should be actively cut down. **	Before	0	1	3	9	2	0	1
	After	6	6	4	0	0	0	0
To maintain satoyama, humans should not change their methods. (Inverted) **	Before	1	3	4	5	1	1	1
	After	8	3	4	0	1	0	0
	N = 16, 7: Strongly Agree, 6: Agree, 5: Somewhat Agree, 4: Neither Agree nor Disagree, 3: Somewhat Disagree, 2: Disagree, 1: Strongly Disagree, ** p <.01							

Table 3: Evaluation Results: Knowledge about satoyama management

As a result, we found participants are able to use this game conveniently. We also found that participants were interested in the problems of satoyama through this game and were able to acquire knowledge about satoyama and satoyama management.

3.2.1 Evaluation by Interview

We interviewed each participant for five minutes. Figure 7 shows a child being interviewed.

We evaluated their described degree of learning support, the operability of the system, and learning results. To evaluate learning support and system operability, we asked participants the following question: “What are the good and bad points of the Satoyama Management Game?” To evaluate the learning effect, we asked participants the following question: “How do you manage actual satoyama?”

3.2.2 Result

We aggregated the results from the interviews described above.

Regarding learning support, 16 participants had positive opinions, and no subjects had negative opinions. Responses included statements such as "the system is very good because we can learn long-term vegetation successions in the real world in a short time" and "like actual satoyama management, the Satoyama Management Game was interesting because it was difficult to manage."

Regarding the interface, four people gave positive opinions, two had negative opinions, and ten were undecided. Positive responses included statements like “the trees are easy to understand" and "the score is easy to see." The negative responses included the following statements: "I could not understand the meaning of the graph" and "insects were hard to see."

Regarding learning effect, most participants understood what is important to actual satoyama management. Some of the responses in this regard were that "when there are many evergreen trees, and they should be cut down" and "deer and insects should be immediately exterminated."

Figure 7: Child during the interview.

As a result, we found out that this game is excellent for learning vegetation succession. In addition, we found that this game has a teaching effect.

3.3.1 Evaluation by Score

To qualitatively evaluate the teaching effect in the Satoyama Management Game, we focused on the last score of the game. The first to sixth game scores were tested using the Friedman test.

3.3.2 Result

A significant difference was confirmed at the 5% level. This showed that the average point score was significantly increased.

This result further indicates that this game has a teaching effect. Table 4 summarizes the game scores of each subject.

Subject	First	Second	Third	Fourth	Fifth	Sixth
A	30	77	61	84	81	82
B	64	66	76	68	69	73
C	62	26	61	52	68	70
D	59	64	40	51	55	61
E	2	56	61	60	73	82
F	56	49	68	78	53	66
G	67	62	73	65	66	66
H	77	53	75	79	52	72
I	63	57	3	69	60	71
J	67	73	78	73	76	75
K	66	78	82	84	74	74
L	54	38	64	69	63	68
M	59	44	62	64	76	70
N	0	65	71	77	76	65
O	17	14	46	72	73	44
P	70	68	62	78	71	74

Table 4: Game Scores of Each Subject

4 Conclusion and Recommendations

In this study, we developed and evaluated the Satoyama Management Game. Using this game to simulating long-term satoyama management, which is difficult to experience in the real world, we are generating interest in managing satoyama, which is a biodiversity environment, and can teach learners about vegetation succession. The results of the questionnaire, interview, and game score evaluation show that the participants' interest in satoyama management improved significantly, and participants were able to learn about vegetation succession empirically. The results also show that participants recognized the importance of managing the biodiversity of satoyama and that this game is excellent as a learning support system for vegetation succession. Furthermore, they suggest that children can become interested in biodiversity and forest management.

This research is an interdisciplinary game development study integrating knowledge in the fields of science education, plant sociology, educational engineering, information design, and information science. In addition, because it is designed using experts in plant sociology, it is highly reliable and reasonable.

The experimental results of this study will have value in learning-game research. In addition, the theme of satoyama vegetation succession could be used as new PBL teaching material on the maintenance and preservation of the natural environment, which is drawing attention globally, and it could contribute to the teaching of these topics internationally.

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