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Development and Application of an Environmental Education Tool (Board Game) for Teaching Integrated Resource Management of the Water Cycle on Coral Reef Islands

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Abstract: To solve resource issues on coral reef islands, an understanding of the water cycle is essential. Water resource management is intricately linked to diverse occupational industries and coral reef ecosystems on these islands. To effectively promote sustainable natural resource management, we developed a board game as an environmental education and communication tool for school students and people of all ages. The concept of the game is that "clean water will always be available if it is used properly". The board game was designed based on an island with an underground freshwater lens as its main water resource. Role-playing was used to enhance islander livelihoods such as with vegetable and livestock farming, fishing, and tourism. Players, while working collaboratively, have to use the island's groundwater adequately and conserve it for future generations. The game was developed through a transdisciplinary process in collaboration with scientists, administrative officers, civic groups, and students. Additionally, the board game was tested in diverse communities. In this study, we elaborated on the board game after it was played by students at an elementary school on Tarama Island. We observed that participants learned that cooperation is important for the sustainable use of water resources. Moreover, the participants proposed two methods for cooperation: joint discussion and 'assembly decisions'. The board game has the potential to be used as an effective environmental education tool to promote sustainable water resource management on coral reef islands.

Keywords: coral reef islands; water cycle; communication tool; environmental educational tool; board game

1. Introduction

A freshwater lens is a convex layer of groundwater that floats above denser saltwater and is the main source of water for many small islands in tropical and subtropical regions. Freshwater lenses may diminish significantly when rainfall is insufficient; therefore, these islands are highly vulnerable to water shortages (Figure 1) [1]. The natural and social environments of the southern small islands are easily affected by weather. Although sunny days are effective for crop growth and tourism, extended periods of sunny weather may trigger water shortages. In contrast, excessive rainfall can cause flooding. Although typhoons generate substantial amounts of water, they may also cause natural disasters such as landslides and salt damage.

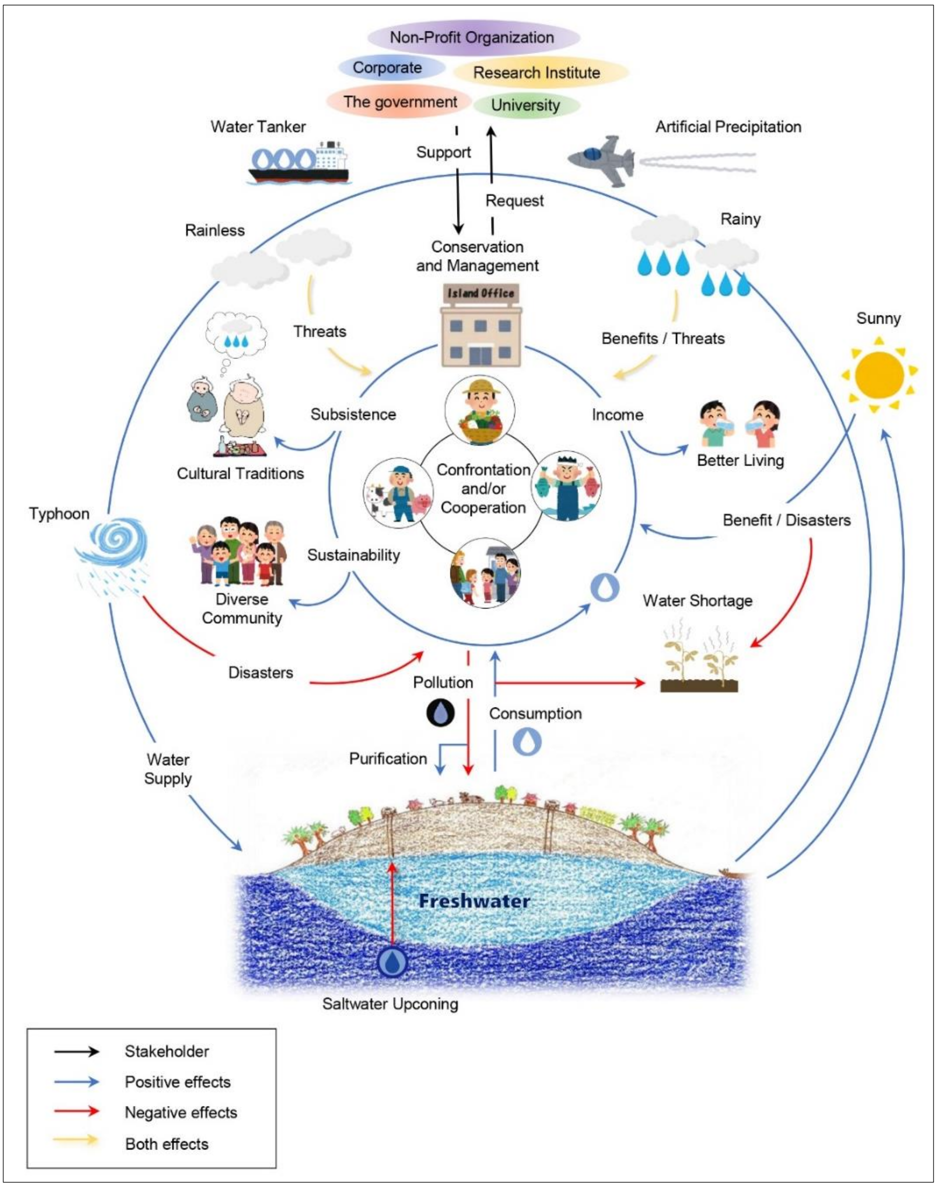

Figure 1. Conceptual diagram of the water cycle in the South Islands of Japan.

The islands in the Ryukyu Arc, Japan (Figure 2a,b) have been divided into two categories, low and high islands, based on their topography and geology. The low islands are mainly comprised of Ryukyu limestone formed from coral reefs [2]. Ryukyu limestone has a high permeability coefficient, thus, precipitation rapidly seeps into the ground and becomes groundwater [3]. The Shimajiri Group, which underlies the Ryukyu limestone, is composed of silt and mudstone, and is an impermeable layer. Thus, groundwater flows along the boundary between the Ryukyu limestone and Shimajiri Group. In coastal areas where the boundary is exposed, springs can be observed along the coastline [3]. Among the low island types, freshwater lenses form when the location of the impermeable layer is deeper than sea level.

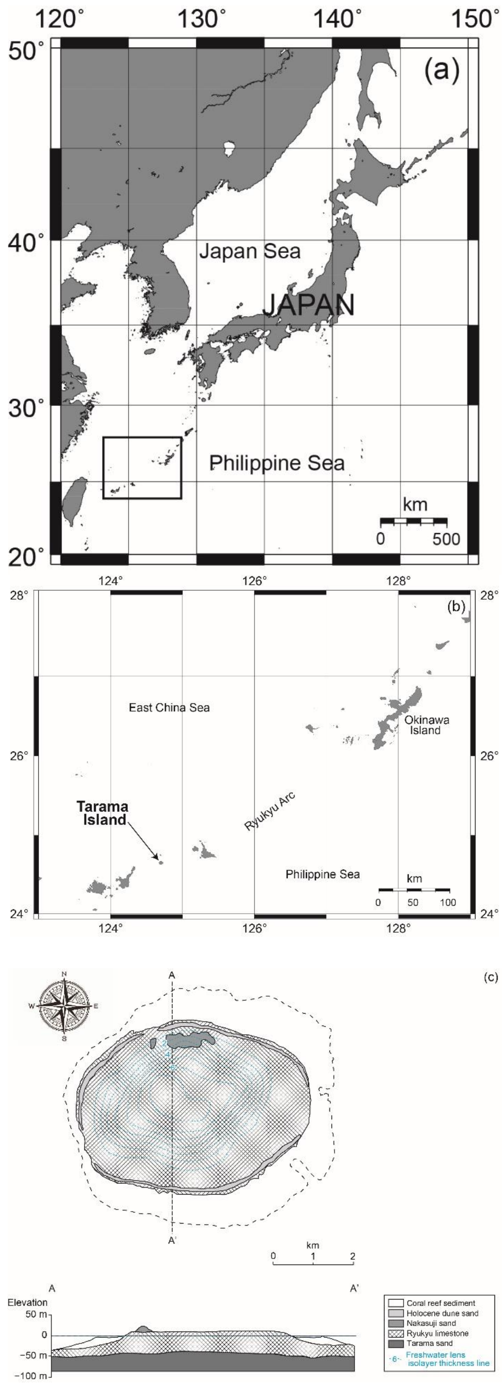

Figure 2. (**a**) Location of the Ryukyu Arc, southwest of Japan. The area indicated by the square box shows the extent of the area depicted in Figure 2b. (**b**) Location of the study area, Tarama Island, in the Ryukyu Arc. (**c**) Simplified geological map of Tarama Island, where the study was conducted (top). The light blue dotted line represents the isopachous line of the freshwater lens, and the number represents the layer thickness of the freshwater lens (m). A-A′ represents the cross-sectional line. The geological cross-section of Tarama Island extends approximately 80 m below the surface (below). The thickness of the freshwater lenses is approximately 7 m at is the thickest, indicating that they are thinly distributed within the Ryukyu limestone geological unit.

Resident livelihoods on small islands depend mainly on agriculture, fishing, and small-scale tourism [4]. Generally, water resources are managed by the island's public office or communities, the central government, prefectural government, other administrative agencies, universities and research institutes, private companies, and non-profit organizations

(NPOs). In addition, organizations outside the islands contribute to water quality management and water shortage countermeasures such as artificial rainfall generation [5], water supply from tankers [6], and water supply from mobile seawater desalination plants [7]. Historically, islands have experienced chronic water shortages and have inherited a culture of rainmaking rituals and mutual assistance within local communities [8]. However, in recent years, the development of residential areas has reduced rainwater infiltration into the ground and increased sewage discharge. In some cases, sewage may be discharged into the sea without adequate purification [9]. Agricultural use of chemical fertilizers has increased the nitrate-nitrogen concentrations in groundwater, which may result in unusable drinking water because of its poor quality [10]. In addition, if large quantities of water are pumped from the freshwater lens, localized seawater intrusion (up-coning) may occur, and freshwater salinity may increase [11].

To address these water resource issues on the southern islands and formulate an island-type integrated water cycle management plan, project "Mizunowa" (the water cycle connects southern island life) was developed as a multidisciplinary project at the University of the Ryukyus in Japan from 2017 to 2019 and was supported by the Japan Science and Technology Agency (JST) Science and Technology Communication Promotion Project Future Co-Creation Innovation. The project aims to: (1) scientifically describe the water cycle characteristics of islands; (2) develop technologies to reduce the environmental impact of human activities; and (3) raise community awareness of water resources.

In this study, we created a board game as an environmental education and communication tool to address Objective 3—community awareness of the regional water cycle. Furthermore, the board game was based on Tarama Island (Figure 2b,c), located in the Ryukyu Arc, Japan. This goal not only includes understanding the water cycle, but also thinking about the sustainable use of water resources. The proper conservation and management of water resources should involve people from diverse perspectives and be a collaborative effort [12,13]. For community members to use water appropriately, there is a need to develop a common awareness of water resources, for which mutual cooperation is important [14]. Board games have been used to build cooperative relationships [15–17]. In this study, we describe the creation process of a board game as an environmental education and communication tool and explore its effectiveness.

2. Board Games as an Environmental Education and Communication Tool

Board games can be used as environmental education and communication tools [18]. Interactive lessons have proven to be effective in learning, especially for students who cannot understand abstract conversations in the classroom [19]. In this context, board games have been developed as learning materials in various fields such as medicine, chemistry, geology, physics, finance, environment, language, culture, history, and sociology, taking advantage of the concept of learning while having fun [20]. The rise in "serious games" (SGs) [21], which aim to solve social problems, has also led to an increase in the number of SGs on local issues, and recently, many regionally-based SGs have been developed (e.g., [22–26]). Although many SGs on water issues have been created [27], few have focused on the hydrological cycles of small islands in tropical or subtropical regions. For example, a water use and management game set in Tarawa Atoll in the Republic of Kiribati considers the elements of highly polluted freshwater lenses and seawater desalination plants [28]. However, the purpose of SGs is to provide information to stakeholders, and their use and effectiveness as a teaching tool have not been discussed [29]. Another game designed to promote cooperation among stakeholders regarding water resources is a role-playing game under the theme of water safety plans [15]. The game is played competitively with communication prohibited between players in the first round, and then played cooperatively in the second round, with increased communication between players. Players can learn the importance of cooperation among stakeholders through the two games. However, while the paper discusses the content of the game and how it should be played, there is little consideration of the perspectives or extent to which players learn the importance of cooperation.

Therefore, in this study, we developed a SG board game for residents of tropical to subtropical small islands to consider how to use freshwater lenses sustainably and cooperate for this purpose. Furthermore, from the perspectives of both developers and practitioners, the following were discussed: (1) the design of the board game; (2) the goals and targets of the board game; (3) the opinions about the actors who decide the "rules" of water resource management; and (4) verification of the effectiveness of the board game.

3. Method

3.1. Design, Development, and Functioning of the Board Game "Sui-Māru"

In this study, the development of a board game was conducted through a dialogue process among people with diverse backgrounds. On this basis, various water users were consulted and the game was developed through mutual understanding and collaboration. The board game was tested with participation from several communities, and issues were extracted and improved based on the opinions of players and practitioners and the observations of researchers (Figure 3).

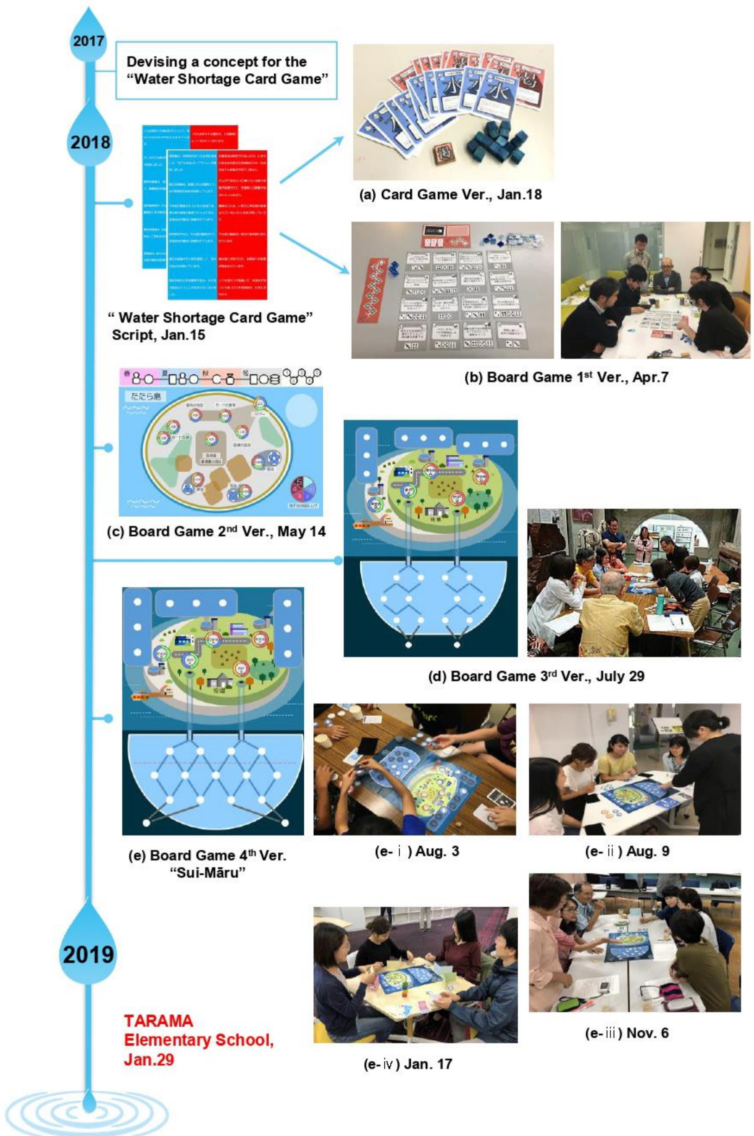

Figure 3. Board game development timeline.

The development process for this board game occurred as follows. First, the developers of this project created a script and prototype. Next, the functionality of the game as a board game and its effects on players were measured through a test-play. The method of measurement was based on the collection of textual data from participant observation, interviews with players, and questionnaires, which were then analyzed and discussed.

Fifty-one people from seven communities collaborated and test-played this board game. Early prototypes in the development process were tested by the project team to examine game methods and policies (Sections 3.1.1 and 3.1.2). The prototypes and direction of the game design and rules were decided and then test-played by cooperating communities to check the functionality and degree of content transfer (Sections 3.1.3 and 3.1.4). The prototypes for which the direction of the game design and rules were established, to some extent, were then tested by the cooperating communities of this project to verify their functionality and the degree to which the aims of the game were communicated (Sections 3.1.3 and 3.1.4). In addition, the board game was modified and tested in another community to measure its effectiveness (Section 3.1.5). Thus, the development process of this study had different objectives for the test-plays at each stage. Given this background of development methods and processes, the methods for measuring the effectiveness for players differed from phase to phase. Furthermore, informed consent was obtained from all participants for the publication of comments and accompanying images involved in the study.

3.1.1. Card Game

Initially, we explored creating a "water shortage card game" (Figure 3a). The first script was written by a researcher among the development members and the game prototype was designed by an administrative team member. The game was tested by seven members of the Mizunowa Project Team: researchers, university students, and NPO members. Currently, the game is still in the early stages of development and is of insufficient quality to have a measurable effect. Therefore, the question of whether card games are an appropriate method for this study was considered.

The game prototype consisted of 10 water cards per player and featured approximately 20–30 event cards. The first step of the game is to distribute 10 water cards to each player and stack the event cards at the center. Each player is expected to select one event card and flip it over. If the event card selected is rain, the player receives one water card; however, when a drought card is selected, the player receives one less water card. If a player receives an administration or scientist card, the player has the opportunity to obtain two water cards. Additionally, on the reverse side of the two water cards, the player must provide an explanation of the role of the government and researchers in addressing water shortage issues and/or the effects of extreme weather events on water resources. This component facilitates discussion and shared learning. However, the game had limitations in that there were no opportunities for players to make decisions; players were restricted to following the instructions on the flipped cards. The concept of the game is that the first player to run out of water cards loses. The game lacked development potential because learning stopped when the game ended; there was no provision for players to change or manipulate the direction of the game.

3.1.2. Board Game (1st Version)

Experimentally, we designed a board game using scripts from the "water shortage card game" (Figure 3b). The test-play of this game was also conducted by the same members as the card game (Section 3.1.1). The purpose of the game was to allow players to cooperate with each other to develop drought countermeasures and solutions. The game consisted of one water storage rate board, 16 drought countermeasure cards, one incident board, 10 incident cards, 10 blue water chips, 10 red drought chips each, and three dice. Players were expected to roll three dice simultaneously and place the number that came up on the drought card, noting that the number should be matched with the number indicated on the drought card's squares. The number of dice that a player could place on a card was limited to two per turn. Each player takes a turn rolling the dice, and if a player can place a water chip on all of the cards' squares, the card is turned over and the drought measure is considered to have been achieved. If the card is not filled, the gauge on the water storage rate board was reduced by one. If the player rolls a "1," a drought chip is placed in the alarm slot on the incident board. When the drought chips are aligned in three incident alarm slots, the player must draw an incident card. If the drought countermeasure displayed on the drawn card is taken (i.e., if the drought countermeasure card is turned over), the game is safe. If not, the drought countdown on the water storage rate board is advanced by one. When the water storage rate reaches zero, everyone loses.

After the test-play, the players pointed out the following issues. (1) The game did not include weather conditions such as rainfall. Therefore, the game only featured a constant decrease in water through a causal relationship such that when the water storage rate decreased, droughts occurred. (2) The game lacked elements related to the water cycle and the water environment, and, based on this, was insufficient as an environmental education tool. However, it was found that a board game was better than a card game in expressing the various positions surrounding water resources, region-specific environmental and social issues, and the complex relationships among these issues. Therefore, we continued developing a board game after this session.

3.1.3. Board Game (2nd Version)

In this version, we created a virtual island modeled after Tarama Island (Figure 3c), with an adopted role-playing method. Tarama Island is the target area of this study and is an island where the main source of water is groundwater, called a freshwater lens [30] (Figure 2b,c). The game was tested by six members of the Okinawa Prefecture Yomitan Village Board Game Club, to which one of the game developers belonged. The members of this club not only play, but also develop various board games; therefore, they have the perspective of both players and developers. In addition, the game developer is also an administrative official, who is highly aware of the state of municipal water resource management.

The game consisted of one main board, one water storage rate board, four player sheets, 20 plan tiles, 10 weather cards, 10 event cards, 10 water supply support cards, five science and technology support cards, four player figures, 20 freshwater panels, 20 saltwater panels, and 50 coins. The players were divided into five groups that depended on water for their livelihoods: vegetable farmers, livestock farmers, fishermen, innkeepers, and tourists. If players earn money by using water, they can obtain a water storage tank. One turn in the game is equivalent to one year. The game can be won if a player can still withdraw freshwater after five turns are completed. If freshwater is not consumed during the game, or if seawater is consumed, the player loses the game. Whether it rains is determined by drawing a weather card. The administration and institute depicted in the game can be requested to provide water-supply assistance. The purpose of the game was to determine a balance between the amount of water withdrawn from groundwater and the maintenance of livelihoods. This version includes seasonal changes in the precipitation.

The following issues were noted by players during and after the tests. (1) Players could not understand how the water cycle on an island works because the main board did not include elements of groundwater. (2) The game structure was complicated because of the diversity of players, stakeholders, and tools. These issues made it difficult to understand the characteristics of each occupation and the specific types of function or support, and the participants deemed it difficult to remember the rules. As this version of the game was also incomplete, it was not possible to measure its effectiveness. On the other hand, players commented that they were able to become aware of water environment problems and social issues in their own municipality by learning about the lives and industries of small islands that depend on groundwater.

3.1.4. Board Game (3rd Version)

This version removed tourists and included only island inhabitants as players. In addition, administrative and scientific support cards were centralized. Moreover, a freshwater lens was illustrated on the main board (Figure 3d), which helped visualize the mechanism by which seawater enters a freshwater lens after it is drawn from a well. The game was tested by 11 members of the "Wakimizu Fun Club", which is a group of citizens involved in spring water fieldwork and information communication. The group collaborates with schools, museums, community centers, and other diverse institutions to conduct various activities to preserve the spring water culture. In addition, they collaborated with the city administration to produce a map of spring water in preparation for disasters. The facilitation and observation of the game were performed by four development members. For the first time, a questionnaire was administered to the participants to identify game issues in this version of the game. The effectiveness of the game was measured through participant observation, interactive interviews, and a paper-based questionnaire.

The questions in the survey were as follows:

1. Have you ever played board games before? (Yes/No);
2. Did you enjoy the game? (Fun/Fairly well/Not so fun/Other);
3. What are the rules and procedures of this game? (Easy to understand/Hard to understand);
4. What did you feel after the game? (Free description);
5. Did you receive the message that this game intended to express, that the unplanned use of water or keeping water to yourself can lead to drought? (Yes/No);
6. Do you think playing this game will encourage people to think about and discuss "water" and "How to use water"? (Yes/No/Cannot say either);
7. Do you have any elements, options, or rules you recommend for the game? (Free description);
8. Free description of impressions and opinions.

Upon summarizing the feedback from the questionnaire, the participants said that the board game provided them with an opportunity to think comprehensively and from multiple perspectives about how the water cycle works on the island, their respective positions regarding water rights, and ethics for improved sharing of water resources. Some commented that they thought the facilitators played a significant role in the practice of the game because they read the game situation in the real world and encouraged their participation. The issues to be addressed are summarized as follows. (1) One player indicated that the illustration of water reduction after groundwater withdrawal was unrealistic, because the freshwater lens depicted on the mainboard had a water tile conductor line divided into two along the two wells. One of the reasons for this unrealistic portrayal was the consideration of fair water withdrawal among players. Because the two wells have water rights, the role of the player determines which wells can draw water. Therefore, we tried to create fairness among the players by equalizing the amount of water that could be drawn from each well; however, this unscientific representation created an unfair situation. (2) The water-intake system of players was based on a turn system, which favored the player who played first. This caused conflict between players and led to competitive gameplaying. (3) By leaving the weather to luck, no rain occurred, which resulted in a drought in the middle of the game. This highlights the issue of ending the game without achieving its intended purpose. (4) Finally, the rules were reported to be too complicated and difficult to understand for first-time players, and the game time was too long.

3.1.5. Board Game (4th Version; "Sui-Māru")

After incorporating the identified issues, the structure of the game was changed to that of a strategic game [31]. In a strategic game, all players simultaneously choose their actions. This method tends to promote competition because players must choose their own actions without observing the actions of other players. However, by modifying the rules, it is possible for players to consult each other in advance (consensus building) on the amount of water withdrawal and allocation of gains. Therefore, the game was redesigned to be both competitive and cooperative. To shorten the game time, the number of tools was reduced and the rules were simplified. Other improvements included the depiction of water reduction after withdrawal from the freshwater lens (Figure 3e). Weather cards were also adjusted to mimic a possible drought scenario in which drought events did not occur quickly. The questionnaire items were the same as in the 3rd version (3-1-4). This version was tested in the following four communities with minor improvements in props and rules.

(i) Boys' Athletics Club: 6th grade students (four people);
(ii) University of the Ryukyus: Students (four people);
(iii) Naha City Community Center: Social education directors (12 people);
(iv) Team AKUAH: Students from the University of the Ryukyus who supported the project (four people).

The player opinions obtained during the above test were reflected in the following improvement measures:

- A water tank was added to the components in response to a request to allow the users to buy water. Because this game concerns groundwater, we added a system that allows players to buy a container for storing water instead of commercial products such as mineral water.
- In response to the comment that there should be a system of fines for failure to obtain fresh water from groundwater, a rule was established that if "seawater" is withdrawn from groundwater, the coins must be given up.
- In response to the comments that players should be able to consult with each other during the game and that players should be able to earn the more they cooperated with each other, we created rules of "competitive" and "cooperative".

The board game used in this study was completed through the process described above.

3.2. Description of the Final Board Game

3.2.1. Naming and Goals/Targets

For island residents to use water properly, which is a common property of these communities, it is important for each individual to improve their literacy of water [32], and through mutual aid, build cooperative societies adapted to the water cycle. Our board game was named "Sui-Māru" to reflect this intention. The term "Sui-Māru" was coined by combining "Sui," a Japanese word for water and "Yuimaru" [33], an Okinawan word meaning mutual help. The main goal of the board game was to inform people that water can be used effectively if it is used properly, and to create an opportunity to discuss water issues on the island. To achieve these goals, the following specific learning targets were established:

1. Some small islands only have rainwater and groundwater as water resources.
2. The amount of water resources depends on the weather and season, and if not used properly, water shortages can occur within a short time.
3. Excessive use of groundwater draws seawater into underground freshwater lenses.
4. Islanders must balance their well-being and livelihoods with the sustainability of their water resources.
5. Water is a common property of the island, everyone must cooperate to preserve and manage it, and that there are people in the community from all levels of society who use the water for their own reasons.
6. Solving water problems requires cooperation and support not only from within the island, but also from outside the island.

By reflecting on the above targets in the design of the board game, we aimed to enhance our understanding of ecosystems and the interrelationships between nature and society through the water cycle (Figure 2).

3.2.2. Board Game Design

The minimum number of players required for gameplay is four (Figure 4); if there are more than four players, the game is played in four groups, or in several tables divided into groups of four players each. The target age was assumed to be ≥10 years old or older. Japanese elementary school students learn about the natural environment and natural resources from around age 10, and therefore have the basic knowledge necessary for game content. However, children younger than the target age can also participate if they understand the content and rules or if they have the support of their elders. Competitive games make players distrustful and prone to selfish behavior [34]; as a result, they tend to run out of public goods, an undesirable outcome [35]. However, in cooperative games, players are allowed to negotiate and discuss water-withdrawal plans. Cooperation is a good way to avoid the depletion of common resources [36], while communication is a good way to do so [37]. Through communication, players learn the importance of cooperation (Target 5).

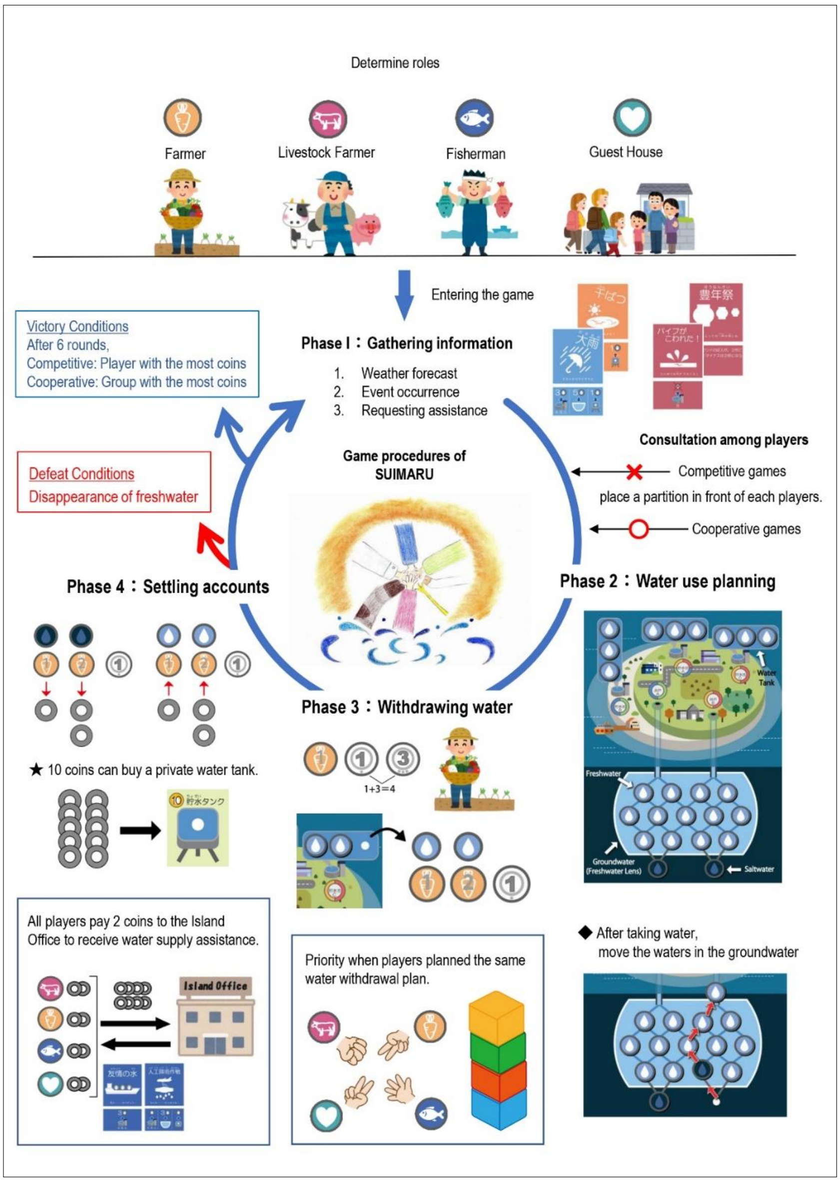

Figure 4. Conceptual diagram of one round.

In this game, the player chooses an occupation or role from among those available on the southern island, especially those in water-based industries (farmers, livestock farmers, fishermen, and guesthouses) (Target 4). Role-playing has the advantage of allowing participants to simulate the circumstances of those in these occupations and to gain a deeper understanding of the problems that must be solved [38]. Next, the order of priority (order of "initiative tower") was determined when the players had the same water intake plan. This is conducted to equalize the winning conditions by alternating the order of priority, since the player with the first turn inevitably has an advantage [31]. Immediately before the game begins, the facilitator shows the picture storyboard (Figure 5) and reads the narration to encourage participant immersion [39]. The main facilitator is responsible not only for facilitating the game but also to help players understand the objectives of the game. Therefore, the knowledge of the water cycle and social environment of the selected region is necessary. On the other hand, assistant facilitators are assigned to support the progress of the game when many people play it, so anyone can play the game as long as they understand the rules.

Figure 5. A picture storyboard was used to introduce the game. While showing the images, the following narration facilitated participant immersion: Narration: (**a**) Sui-Māru, do not let the drought get you down! TATARAN-CHU (people on TATARA Island). (**b**) On a small island in the south of the Pacific Ocean, inhabitants live peacefully in a rich natural environment surrounded by a beautiful sea. However, life on the island is difficult because the inhabitants suffer from water shortages. (**c**) The only water on the island comes from cisterns that store rainwater and groundwater that has soaked into the ground and accumulated underground. Therefore, if it does not rain for some time, the water available on this small island will be low. However, inhabitants sometimes use too much water to meet their own needs. When this occurs, the water in the reservoirs runs out and seawater enters the groundwater. (**d**) Can the inhabitants use water, which is the property of the island, with care?

Each game consisted of six rounds, with each round comprising four phases. The reason for dividing the round into phases was to separate them into various situations that occur within the water supply–demand cycle, so that the participants could focus on what they should think about as each phase progresses. Separating games into phases is a feature of SGs with complex structures, making the game structure simpler [40]. In the real world, the scene also changes; it rains, water accumulates, and the player uses the water, encouraging them to think about each scenario while making associations to daily life. One game with six rounds was used to represent the change in seasons. One round corresponds to one month, with six rounds of six months each. Through the progression of rounds, participants can witness how the weather and seasons change. For example, Japan experiences a rainy season in May and July and typhoons in July and September. Typhoons occur approximately once per month and move across Japan, causing damage from floods and storm surges. In addition, during the rounds, sudden accidents such as water pipe breakages may occur, and a large number of tourists may increase the water usage [41]. In the first half of the year (six rounds), the games were played competitively, whereas the second half was played cooperatively. This approach allows players to experience iterative learning, whereby they learn winning strategies by observing each other's behavior in the first half of the game and then applying them in the second half [15].

After the game, everyone had a reflection session [42,43]. After two games, players learned that a group of people sharing resources is called a "society" and that people compete and cooperate in such a society. This is connected to the concept of resource-use conflict. Hardin (1968) argued that all resources would eventually be depleted if individuals or members of a society used common resources for their own gain and with no regard for others. On the other hand, it is easy to gain when you think of everyone else and help each other [36]. Through the participants' own experiences, they can comprehend that it is easy to lose as a result of thinking only about "me" [35], and that each of the members of the society are likely to benefit when they help each other while thinking about "everyone" [36]. Furthermore, since the rules are different for the competitive and cooperative games, players will be able to realize the importance of considering that the "rules" can change the outcomes. Finally, the game was designed to show that the island has rules for water use that were created to help everyone live together and to elucidate the existing rules.

3.2.3. Components of the Board Game

The game set consisted of one main facilitator and four assistant facilitators, a set of four picture-story boards (Figure 5), four main boards (Tatara Island map), 38 water panels, 36 saltwater panels, 20 weather cards, four help cards, 12 plan tiles (3 for each player), one set of initiative towers, 200 coins, four water storage tank cards, four newspaper article panels on droughts (Appendix A), and four partitioning screens (used only in the competitive games) (Figure 6).

The main board depicts the town hall, port, three public reservoirs for storing rainwater, and two public wells for extracting groundwater. The water tiles are placed on public reservoirs, public wells, and private water tanks, and represent the number of water panels a player can withdraw. To indicate that the saltwater was drawn into the freshwater lens, a saltwater tile was placed on the freshwater lens when the water tiles were taken (illustrating saltwater intrusion). There were five types of rain weather cards (rain, light rain, long rain, heavy rain, and narrow range rain) and 15 cards with different probabilities of precipitation ranging from 10% to 90%, which were used at random. There were two sunny cards with 0% and 10% chances of precipitation, two typhoon sheets with 90% and 100% chances of precipitation, two dry rainy season sheets with 0% and 10% chances of precipitation, and one drought sheet with 0% chance of precipitation. The help cards represent interventions and are used to request water supply assistance from the island's administrative office in the event of a drought crisis. There were four types of assistance/intervention: water tankers, artificial precipitation, mobile desalination plants, and prayers for rain. Each player used a set of three plan tiles. The front tiles were colored and the back tiles were gray, with numbers on both sides. Players combined the numbers on the front and back of the plan tile to devise a water-usage plan. The initiative tower was created by stacking blocks of the same color, following the color of the occupation/role to form a tower. Occupation with the topmost color represents the priority of water usage rights. Coins represent money earned (economic benefits) after water withdrawal. Water storage tank cards were purchased privately. A partitioning screen was used to conceal a player's actions during competitive games. Newspaper articles on drought were used as Appendix A to provide information to the players on what could happen to the islanders if the freshwater lens is depleted (Appendix A).

Figure 6. Board game equipment used at Tarama Elementary School. From the top left, blocks of colored wood, which were used as the initiative towers. The coins in the green bowl represent money. The cards represent the water storage tanks. Next, are partitioning screens. The round panel at the lower left represents water (the light blue panel at the top represents freshwater, and the dark blue panel at the bottom represents saltwater). The large image on the left center is the main board (the upper half represents the onshore portion of the island, whereas the lower half represents the freshwater lens, and groundwater shows up-coning, whereby seawater rises from below). The round tiles slightly above the upper-right center are the plan tiles (red means livestock farmers, yellow means vegetable farmers, green means guesthouse owners, and blue means fishermen, who use water panels for the number written on each). The dark blue cards are the support cards (four cards from left to right: mobile desalination plant, prayer for rain, water tanker, and rainmaker). Two rows of weather cards (black: sunny; orange: dry rainy; blue: typhoon and long rain) are lined up in the lower-right center. The red cards in the two lower right rows are "event cards" (they show water-related events such as harvest festivals, pipe breakage, and instructions on how to increase or decrease the number of water panels).

3.2.4. Procedure

Before starting the game, the players set the main board and the components of the board game on the table. They then selected their occupation, which can be decided by discussion, rock paper scissors, or any other method.

Phase 1: Weather forecast

This phase involves the occurrence of unforeseen events, and the status of water resources is dependent on the weather (Target 1) and the use of water wells in preparation for unexpected water needs and withdrawals (Target 4).

Phase 2: Water withdrawal plan

This phase involves water management using water withdrawal plans symbolized by the use of plan tiles (a combination of gray numbers on the reverse side). The phase is conducted in both competitive and cooperative games, and is based on the information obtained in Phase 1. In a competitive game, a partitioning screen is used to conceal a player's action or strategy, which is only revealed by the facilitator's instructions. In contrast, the cooperative game does not involve partitioning screens, and water is withdrawn (Targets 4 and 5) once the players have made their withdrawal plans. This changes the water availability on the island, and seawater is withdrawn when players decide to withdraw groundwater [11] (Target 3).

Phase 3: Withdrawing water

In this phase, the gray numbers on the reverse side of the planning tiles are summed, and the player with the highest number performs the following actions: first, the player takes a water panel from an identified public reservoir or public well. If the player has a private water tank, the player must first take water from it. Similarly, if the player has a private water storage tank and there is a water tile, the player must first take water from it. Next, the water panel that is taken is placed on top of the tiles that are on the surface (colored) of a plan tile. Players repeat this, even for saltwater panels.

Phase 4: Settlement of accounts

The fourth phase features an element of accounting, in that a water panel on the plan tile is exchanged for the number of coins indicated on the plan tile. For example, if a saltwater panel is used, the number of coins is forfeited. A weather forecast was also run, and as a result, the amount of water in the reservoir as well as the groundwater either increased or decreased (Targets 1 and 2).

3.2.5. Victory-or-Defeat Conditions

In the competitive mode, the victory condition was determined for the player who earned the most money at the end of the game. In the cooperative mode, the group that earned the most money at the end of the game won. The condition of defeat is that everyone loses when all freshwater lenses are transformed into saltwater in both game modes.

4. Conducting the Board Game

The board game was practiced with 5th grade students (n = 10) at an elementary school on Tarama Island. Tarama Island is a small southern island with a typical freshwater lens as its water resource (Figure 2a,b). The island is located 24°39′ N and 124°41′ E in the Ryukyu Arc and has an area of 19.75 km^2 and an average elevation of approximately 10 m, making it one of the islands with flat topography (Figure 2c). The island has a tropical rainforest climate with a mean annual temperature of 24.3 °C and mean annual precipitation of 1943 mm from 2003 to 2020 [44]. Its aquifer occurs within the Pleistocene Ryukyu limestone, in which the underlying Pliocene Tarama Sand Formation forms an impermeable substrate [30]. Seven observation wells are installed on the island, and the aquifer is 50–60 m thick, in which a freshwater lens is formed [30]. The freshwater lens is approximately 7 m thick at the center of the island and thins outward from the coast [45]. On the island, water has been drawn from four wells since 1973 with the intention of using this water supply for agriculture in the future [46].

The board game was conducted in line with one of the school programs, titled "Why? Really? Tarama is a treasure island of science!" This integrated learning program was developed for fifth graders at Tarama Elementary School and was conducted in a series of six omnibus classes. Through these programs, students learned about the water cycle characteristics of the island and the connection between land and sea through its underground water channels. The themes of the classes followed the order of island geology, groundwater (freshwater lens), and aquatic organisms (foraminifera) for the learners to systematically comprehend the water cycle and coral reef ecosystem of the island. These classes addressed not only scientific knowledge, but also the impacts on nature and ecosystems caused by human activity. At the end of the program, the students played this board game to consider water resource management from the perspective of various livelihoods (Figure 7).

Figure 7. Practical at Tarama Elementary School. The main board and initiative tower are placed in the center (in the initiative tower, the occupation at the top has priority to take water when there are conflicting water withdrawal plans. In the scene shown, the order is green–red–yellow–blue, so the order of priority is farmers, guesthouses, livestock farmers, and fishermen). The participants enjoyed placing their favorite trade names on the red, yellow, blue, and green paper strips. The members sitting in front of each paper strip formed a team and have water-taking competition among the teams on one island. This was an example of a competitive game. The person on the right side clasping their hands together is one of the members of Team AKUAH who facilitated this game.

In terms of how the game was conducted, students played in competitive mode on one main board under the theme "my livelihood and water". The students were divided into three to four groups of livestock farmers, fishermen, and guesthouses, with one project member acting as a vegetable farmer. Additionally, one assistant facilitator joined each student group. Subsequently, students played in cooperative mode under the theme "livelihood for everyone and water". In the cooperative game, students were divided into three groups, similar to the competitive game, representing the east, west, and south of the Tatara Islands, and played against each group. Prior to the board game, students researched the water usage of vegetable farmers, livestock farmers, fishermen, and guesthouses. The students then interviewed family members or neighbors and recalled their own experiences before class. After the class and role-playing game, reflection reports were collected from students to measure the effectiveness of the board game. Keywords related to the goals and targets of the board game were extracted from these descriptions.

Words and expressions were extracted from the students' written impressions, and the frequency of keywords related to the study's goals and targets was tabulated. In addition, with reference to the co-occurrence analysis between words, the results were classified into three categories and presented in a pie chart (Figure 8).

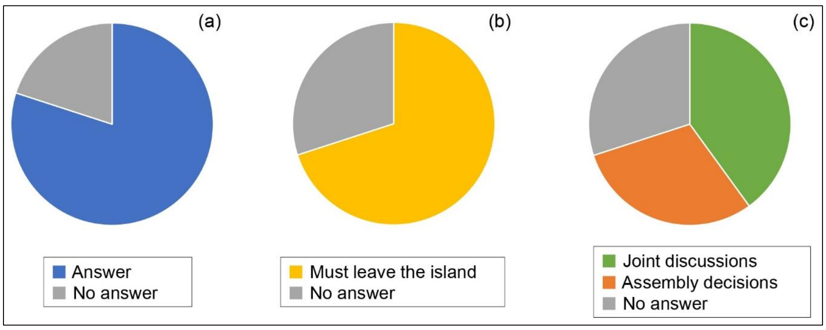

Figure 8. Results of the questionnaire analysis. Classification and percentages of the student statements in the questionnaire on (**a**) whether water should be used carefully, (**b**) why they thought water should be used carefully, and (**c**) how they would use water carefully.

5. Results and Discussion

5.1. Game Winners and Losers

The first competitive game resulted in 59 coins being won for all farmers, livestock farmers, fishermen, and guesthouses (Table 1). No water panels remained for the freshwater lens, and were filled with saltwater panels. In the next cooperative game, East Tatara Island had 64 coins, and only four water panels were left. West Tatara had 70 coins and one water panel. South Tatara had 71 coins, and one remaining water panel. Southern Tatara Island earned the most coins and won the game. In addition, the East Tatara Island group, which had the most water panels left, requested water supply assistance from the Island Office by contributing coins after consultation among players at the time when they anticipated a water shortage. In contrast, the South and West Tatara Island groups narrowly escaped water depletion, and the game ended with only one remaining water frame.

Table 1. Victory-or-defeat table for the game.

	Competitive	Cooperative		
Island	**TATARA Island**	**East TATARA Is.**	**West TATARA Is.**	**South TATARA Is.**
Total coins earned	59	64	70	71
Amount of water left	0	4	1	1

5.2. Description of Reflection Reports

Eight out of ten learners authored reports on "Use water carefully" or "Water is important" (Appendix B). Seven learners authored reports regarding "if we take too much water, we will have to leave the island". There were five pupils who wrote on "freshwater lenses". Another three described the freshwater lens as "if you use too much water, you might be drawing in saltwater" (referring to saltwater intrusion). Four pupils described the importance of cooperating to clean water, and one described managing water by limiting its use. In addition, three children described specific arrangements for managing water as "should be decided by the village mayor/council". Furthermore, reflection reports also mentioned other statements such as "There is a need to use the water on the island efficiently", "The board game was great because I could learn while having fun", "I earned more money in the second game than in the first game after discussing and working together to use the water", and "I was able to pass the island to the next generation through cooperation".

5.3. Significance of the Two Practices: Competitive and Cooperative Mode

In this study, we designed a single-board game that could be played both competitively and cooperatively. In the competitive game, players were prohibited from knowing the water withdrawal strategies and action choices of other players before the game commenced; hence, competition for water between players was created. Consequently, the freshwater lens was depleted and replaced by saltwater. In the cooperative game, players consulted with each other on their water withdrawal strategies, and everyone was able to earn more money than in the competitive game, while still having water available in the freshwater lens.

A factor that may have contributed to the better results of cooperative games is that the iterative learning process was successful [15]. Furthermore, the fact that conflict and cooperation were created with only a change in one tool (the partitioning screen) and one rule (communication) is assumed to have made it easy for pupils to compare the two games. This enabled the pupils to understand the disadvantages of a lack of cooperation and the advantages of cooperation. In particular, cooperative games allow players at different positions to discuss better choices for their communities. Such dialogue presents an opportunity to foster solidarity among players. Hence, it can be argued that the board game functioned as intended.

5.4. Discord between the Goals/Targets and the Messages Received by the Students

Students understood the first goal of the board game based on the dominant and most common message that "water can be used sustainably if it is used properly" (Figure 5a). However, further examination showed that the goal had changed from "use properly" to "use carefully". The subtitle of the game, "Don't Lose to Drought, Tatara Island!" may have contributed to the emphasis placed on water conservation. This may have led to the statement (Figure 5b) that is more focused on the future impact of improper water use and management ("if we use too much water, we will have to drink seawater and will not be able to live on the island"). In other words, the students thought that if the water supply was depleted, people would have to drink saltwater and would not be able to survive on the island (touching on the issue and challenges of water availability in a small island context). Therefore, they reported that people should carefully use water. Another factor that led to this logic is likely the strong negative impression created by the real drought evacuation that occurred in the 1960s, which is referred to in the Appendix A. The event resulted from technological limitations and the measures taken at the time, and may not be applicable in a modern society with well-developed logistics and information networks. However, this threat likely made an impression on students (Figure 5b). Such threatening messages are generally true for environmental issues (e.g., IPCC, 2022 [47]).

The goals and targets of the board game were to show that freshwater can be used sustainably if used properly, and the intention was for students to aspire to a brighter society—one that goes beyond sustainability through the effective use of water. However, the design of the board game requires narrowing the targets [48]. For this game, the statement for Target 2, "If we do not use the water well, we will run out of water" was vague and it was realized that the only way to use water effectively was to increase or decrease the amount of water intake (Section 3.2.2). This inevitably led to the conclusion that the only solution to "using water well" was to save water. Consequently, it is possible that the aim of this board game was water conservation within the island context. For example, on Tarama Island, the critical importance of a freshwater lens appears to have already been recognized in 2013 when the freshwater lens was explored for agricultural use [46]. Therefore, the game was designed to encourage the identification of strategies/solutions for using water sustainably and efficiently and could likely be a game for creating awareness of the importance of water conservation.

5.5. Two Different Directions Presented on How to Manage and Use Water Resources

Extracted descriptions from student written reports on how to conserve water showed that 40% referred to "joint discussion". This is presumably because when the results of the competitive and cooperative board games were compared, more water was left in the cooperative game. In the reflection session, students described other groups as opponents competing for water in the competitive game, as opposed to allies who used water together in the cooperative game. These factors may have led participants to express their cooperation. On the other hand, the results showed that 30% of the participants referred to the mechanism for "assembly decision-making for using water" (Figure 5c). This result may have been derived from the discussion in the post-game review session on "Who decides the rules of society and how?". Interestingly, students who played the same games and participated in the reflection session had different solutions: bottom–up approaches were identified for the game sessions, whereas top–down approaches were identified for the reflection sessions. The reason for these impressions is not because they thought spontaneously, but rather because the winning strategy of the game was to "cooperate". Furthermore, during the reflection session, the facilitator provided information on how the assembly decided how to use the water. However, despite receiving the same message, 40% of the responses to the question "how to use water carefully" were to cooperate with each other, while 30% wrote "adults decide," with this group even thinking about the social system. Tarama Island has a "children's assembly system" that allows junior high school students to ask questions in the assembly [49]. This kind of system provides all children with equal access to information, which encourages active participatory governance. Thus, it is expected that the information received is the same for all, and that the differences in the interpretation of the meaning are based on the recipient. This was a limitation of this study because we did not consider the individual characteristics. Thus, further analysis of the outcomes of this game should focus on the individual's cultural background and perceptions [24,50]. In this study, it is possible that the strength of community awareness and dynamics of social systems may have influenced the results; therefore, addressing this limitation is necessary in future studies.

5.6. Sustainable Water Usage as Perceived by the Players

One student described winning the game as "I was able to pass the island to the next generation through cooperation' (j; Appendix B). This is considered as a description of the student's understanding of one of the targets of this board game ("balance to sustainably secure water resources", Target 4). The defeat condition, "when there are no more water panels on the island, everyone loses", was intended to make students aware of sustainable water usage. Through this, we attempted to convey the importance of having such a concept as well as the mechanisms and ways of contributing to the formation of a society that transcends generations. Creating student awareness of sustainability is not an easy task; however, the inhabitants of Tarama Island possess a culture of respect for ancestors and family lineages [51]. Because of this cultural background, it is possible that on this island, even children are familiar with the concept of intergenerational equity and contribute to it.

Another student communicated the trend of low summer rainfall on Tarama Island and suggested that water be conserved to prepare for this event (h; Appendix B). An example of this in the game is the summer season having less rainfall. The student likely considered hypothetical events in the real future and considered risk avoidance.

One student described the water source on the island from a different perspective: "If we use too much water, we will run out of water from the reservoirs" (f; Appendix B). Because the reservoir of Tarama Island was depicted in the board game, the student perceived it as familiar and identified it as an important water source, similar to the freshwater lens.

5.7. Degree to Which the Scientific Message in the Board Game Was Communicated

The statements in the previous section were obtained individually and were not generalized (Appendix B). Scientific concepts had extremely low transfer rates amongst students compared with the findings discussed in Section 5.4 such as "use water carefully" and "use water carefully" because "if we don't use water carefully, we must leave the island", as discussed in Section 5.5. This result could be attributed to either the design of the board game or the way in which students perceived it. Possible factors from the perspective of students include their ability to observe the game board and their understanding of the game. In particular, scientific phenomena such as up-coning may depend on whether the student has an interest in scientific phenomena, while the ability to comprehend the game board and game mechanics, which requires a long-term perspective, may depend on individual characteristics such as whether the concept is familiar to the student. In addition, because the reports were based on the students' own reflections, the content of their reports may also be dependent on their writing abilities [24,50]. In the future, the individual characteristics of the participants should be understood to analyze the effectiveness of the learning program using this board game.

5.8. Overall Evaluation of Board Games as a Teaching Material

In this study, two main goals and six specific targets were established for the development and experimentation of the board game. These include knowledge of the water cycle and social issues that should be considered to promote sustainable water resource management on coral reef islands. Although there were several design flaws in one of the main goals of the program, "using water properly", it was evident that the students understood the importance of "using water carefully" (Section 5.4). The other main goal, which was a discussion of water issues, was supplemented by a reflection session after the board game (Section 5.5). Regarding Targets 1, 2, and 3 on the water cycle, most students appeared to have understood how freshwater lenses and the climate of the island work (Section 5.6). Regarding Targets 4, 5, and 6 on community building for water resource management, some students used the terms "consultation" and "cooperation" to describe the importance of consensus-building, after comparing the competitive and cooperative modes of the game (e.g., i, j; Appendix B). One student evaluated the learning effects of the board game and communicated that it was an interactive way to learn the importance of water conservation (c; Appendix B). The students mentioned one or more of the specific targets of the board game in their reports. Based on the above, this board game is an effective educational tool to encourage students at Tarama Elementary School to think about the use and management of the island's water resources. However, because the effects shown in this case study were limited, the future task is to prove the generality of the study. Therefore, we plan to develop and implement a board game modeled on a small island. Although water resources on different islands may not necessarily be freshwater lenses, these cases can be replaced with different forms of groundwater. Although the subject of this study is water resources, in a broad sense, the theme is the limited environment and resources of the southern islands. Thus, it can be generalized to other shared resources such as energy and food, or to different stakeholders, depending on the local realities.

6. Conclusions

In this study, a role-playing board game focusing on freshwater lenses was developed and used as an environmental education tool to understand the water cycle and its dynamics on the southern islands of Japan. The third game was played both competitively and cooperatively by ten fifth-grade students from Tarama Island, which has an underlying freshwater lens.

In the reflection session, students learned the rules while discussing their impressions of the game. According to their reflection reports, most of the students recognized the importance of water. However, they did not understand that the use of water was important. Several factors may have contributed to this including the fact that the game was designed with only one water intake control, the title of the game evoked the idea of fighting a drought, and complementary newspaper articles about droughts may have created a strong impression. It was suggested that the role-playing game should reconsider approaches that dissuade "threatening" language in communications. Therefore, we suggest that the board game design should be improved so that players can envision a brighter future.

Through their participation and reflection, students provided two directions for water conservation. One was a bottom–up approach, in which all members of the community cooperated, and the other was a top–down approach, in which the council and island mayor led water conservation efforts by enacting ordinances and exercising authority. These are all necessary perspectives for building a cooperative society adapted to the island's water cycle. Nevertheless, it is interesting that the opinions expressed had different orientations. Future research should conduct surveys to determine the individual characteristics of the participants.

The present board game, which reflects the regional characteristics of the islands, was effective as an environmental education tool to consider familiar water issues. This suggests that because water cycles and issues vary among regions, environmental education tools that generate solutions to regional issues should be tailored to the circumstances of each region. Hence, these tools should be designed to convey constructive messages to users for a better future.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Newspaper Articles


(a)
鹿児島から愛の水届く
第一便四十トン
水ききん地域に優先配分

(b)
こんどは広島の水
水不足みかねて
寄港の日富士丸が贈る

(c)
「水」に追われてついに疎開
久高島から本島へ
ひあがった田畑を捨て
井戸の前に徹夜の行列
老人に預けられる子供たち

(d)
人工降雨 カラ振り
福地ダム上空雲なし
気象条件よければ "今後も続けたい"
ドラム缶13本分散水したが…

Figure A1. (**a**) An article on the arrival of a water tanker (water of friendship) from Kagoshima Prefecture (2 June 1963, Ryukyu Shimpo). (**b**) An article on the arrival of a water tanker from Hiroshima Prefecture (Ryukyu Shimpo, 4 June 1963). (**c**) An article on drought evacuation on Kudaka Island (4 June 1963, Ryukyu Shimpo). (**d**) An article on the failure of rainmaking (19 October 1981, Ryukyu Shimpo).

Appendix B. Student Impressions

(a) I learned that water was the most important. I learned that if all the water in the island's freshwater lens transformed from freshwater to saltwater, I would have to leave the island. I learned about these two things and realized that I need to use the island's water more efficiently. If Tarama Island were to encounter such a situation, I would have to evacuate the island, which I do not want to do. Therefore, I have decided to take better care of the groundwater on this island so that I would not be in such a situation. When I grow up, I want to encourage people who do not know about the need for water conservation to take better care of the groundwater.

(b) I learned that if I ran out of freshwater lens, I would not be able to survive there. I also learned that if the freshwater lens is filled with seawater only, the seawater will have to be used. Drinking seawater would cause hallucinations, so I would no longer be able to live on the island. If the freshwater lenses on Tarama Island were to run out, I would have to leave. Therefore, I have decided to use water carefully so that freshwater lenses would not disappear.

(c) I have found that I use water a little at a time. This is because Tarama Island, like TATARA Island, has a freshwater lens that limits the amount of water that can be used. Thus, I decided to use the water carefully. Then, I realized that if the freshwater lens contained only saltwater, I would have to leave because I could no longer live on this island. I thought this board game was great because I could learn while having fun. The game was more enjoyable to play cooperatively than competitively. I will play this board game again.

(d) First, I played the game without understanding what it meant, but the second time I was able to do the occupation I wanted to do and understood the rules. I understood that when there is no more water on TATARA Island, there will be only seawater and no more people. I thought that if the water runs out, seawater will come from a different place, and people will have to drink seawater—I do not like it. When we were divided into three teams to play cooperative games, I was worried because I did not know much about water, but I was glad that the person next to me taught me. In addition, it was good to learn from the university professors. I wanted to play the board game again.

(e) The freshwater lens (groundwater) is important. The reason is that if the freshwater lens disappeared, life would be impossible on Tarama Island, and all the people who lived in Tarama would have left. In the board game, we divided the participants into four occupations: animal husbandry, farming, guesthouse management, and fishing. In the first round, everyone was self-centered; however, in the second round, we fought separately on each island and were able to consult with the islanders, which helped us win. From now on, I will consider other people's feelings before speaking.

(f) I learned that using too much water was not sustainable. The rule is that if water runs out of the freshwater lens, the game is over, and if that happens, people on the island will not be able to live there. If too much water is used, reservoirs will also run out of the water. What I heard about the rules of Tarama Island is that there is currently a freshwater lens on Tarama Island, and that we are not allowed to take water from that freshwater lens without permission. I also learned for the first time that permission from the council was required to take water from the lens. I also learned that the mayor and council members worked together to decide on the rules of Tarama Island, which I had thought were decided by the village mayor.

(g) I learned that using too much water was not wise. The rule is that if water runs out of the freshwater lens, the game is over, and if that happens, the people are on the island. In the first game, we could not consult among occupations, so all groundwater was turned into seawater. In the second game, we were able to consult with each other on each island, and we were able to discuss various things and even change what we had decided once so that we would not run out of groundwater. We were only able to keep one piece of groundwater, but I was happy because we were able to earn the most money among the three islands and received the "Sui-Māru Prize". According to Mr. Kubo, when we discussed the board game and used water together, we were able to earn more money than at first, and so I thought it would be good to cooperate.

(h) I thought it was better to use the water carefully. Because Tarama Island does not receive much rain in the summer, I want to store water. I found that when water is scarce, people prioritize their own lives. I thought that when I ran out of the water, I would buy it from the store. I want to conserve water and do something to benefit my village.

(i) If people do not cooperate, the water on the island will run out and become full of seawater. When this happens, I realized that people will disappear from the island, which will be serious. Therefore, I thought that the second game was better than the first because the four professions cooperated. Therefore, I decided to carefully use water. Finally, Mr. Kubo told me that Tarama Island also discussed and set rules with the council members and the village mayor so that water would not run out, and I decided to eliminate the waste of water.

(j) I learned to use water with care. I did fishing for the first time and guesthouse management for the second time. It was good to learn how to use water. The first time was competitive, and at that time I was greedy because I could not cooperate. However, the second time I was able to consult with them, I was able to cooperate with them. In doing so, we were able to hand the island over to the next generation. If I am on Tarama Island when I grew up, I would like to be the village mayor, and limit the amount that everyone can use.

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