Doctoral dissertation

A study of the researcher's expertise in environmental education for elementary school students

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2021.2

Abstract

Universities are expected to play a role in collaboration with elementary and junior and senior high schools, as a core of the environmental educations in the regions. This thesis showed the characteristics, positive points, and sensitive matters of implemented programs in elementary schools when university researchers were involved in environmental education as academic professionals. The target of the study is environmental education programs for upper graders of elementary school developed and implemented by university researchers in *Yama no Gakko* (2015-2018). *Yama no Gakko* is an educational activity implemented in collaboration with the Hokkaido University Graduate School of Environmental Science, Hokkaido Coca-Cola Bottling Co., Limited, and elementary and senior high schools in Sapporo city.

Chapter 2 investigated whether the educational material used in the programs, which represented groundwater using Lego® blocks and sponges, adequately represented the knowledge of hydrology. This educational material represents the three-storages tank model commonly used in hydrology. It helped children understand that “Forests are a major groundwater recharge area” and “Groundwater has a longer residence time than surface water.” Water sprinkling experiments confirmed that the educational material showed the storage volume and residence time well that should be represented in the three-storages tank model. the amount of water outflow, which changes over time, was measured with a kitchen scale and the weight display was video recorded to visualize the measurement for children as well as in this study. Through those experiments, it became clear that this educational material is that children can learn scientific knowledge effectively, even if this is made of inexpensive materials that are available to everyone.

Chapter 3 discussed environmental education programs and clarified the following. (1) The programs had a process similar to the structure used in academic research (IMRaD structure). Before the experiment, the university researcher had the children make observations and predictions about the results of the experiments, but he did not do enough to get them interested in the experiments, etc. (2) Scientific explanations were provided in the observations and experiments using familiar materials so that the children would be familiar with them and anyone could make them. The educational material was used with familiar materials, and it was consistently effective in understanding scientific

knowledge (For example, if gravel was used in the educational material described in Chapter 2, people could easily imagine its' characteristics in the material, but scientific knowledge of what the sponge represents is required). Therefore, it is difficult for elementary school teachers to master it by themselves due to the requirement of understandings backed by scientific knowledge of natural science in explaining. (3) Two resources, the research network and the creative mind of the researchers, were utilized in the development of the program. The university researcher found the collaborators from his research network and developed new programs with their help. It is also critically important to give researchers "the discretion to exercise their own creativity" when they participate in program development. It is also essential to clearly define the division of roles among the stakeholders so that university researchers can focus on program development.

These discussions revealed that university researchers have been able to create new, academically credible educational materials using familiar materials and to implement lessons that teach scientific knowledge to children and why they were able to do these things. In order to improve the environmental education programs in the future, or to enable elementary school teachers to do these programs as well, elementary school teachers need to lead their students to get interested in the experiments and observations beforehand. To achieve this, it is essential for elementary school teachers to have opportunities to learn scientific knowledge and teaching techniques, for researchers to inform elementary school teachers about the details of the programs beforehand, and for them to understand what each other values.

ACKNOWLEDGMENTS

The “*Yama no Gakko*,” an educational program, was born from my idea that environmental education for children should be based on scientific knowledge. I have been participating in it as its coordinator. I began my research by expecting that I would contribute a little to the advancement of environmental education if I could write my doctoral dissertation summarizing the key points of this program. However, when I started my research, I had a tough hard time deciding how to organize my study about this program. I thought of several stances, such as summarizing a strategic collaboration among companies, NPOs, and universities to challenge social issues, or deepening the educational material, the top part, developed in “*Yama no Gakko*.” Finally, I reached my stance discussing the features of programs designed by a university researcher for upper graders of elementary schools. It took me several years to formulate this “research question.”

I would like to express my deepest gratitude to Professor Yasuhiro Yamanaka for his guidance throughout my doctoral dissertation research. As a working graduate student, I skipped the master’s program and entered the doctoral program. He recommended me to join the doctoral program of the Graduate School of Environmental Science. After I enrolled in graduate school, he enthusiastically supervised me, from starting how to conduct my research in graduate schools, including the primary manner of writing a dissertation, to completing my dissertation. I am convinced that the writing of my doctoral dissertation has given me the real pleasure of research and added an element of “academic research” to my life from now on.

Associate Professor Junjiro Negishi of the Graduate School of Environmental Science was a crucial person in developing programs in “*Yama no Gakko*” and provided the subject matter for this dissertation. The creativity and ingenuity in giving different programs each time for elementary school students was always a surprise to all involved. Looking at the joy of children touching scientific knowledge was my greatest pleasure this program has given. He also gave me discussion time for my doctoral dissertation. I would like to express my deepest gratitude to him.

The students from Negishi and Yamanaka laboratories who participated in these activities gave me their opinions on the programs at the review meetings after each program. The feedback from Ariake Elementary School teachers regarding the programs helped me deepen discussions in my doctoral dissertation. The staffs of the Public Relations and CSR Promotion Department of Coca-Cola Hokkaido are members who have worked together to develop "*Yama no Gakko*." They also cooperated in my interview with teachers at Ariake Elementary School and gave me feedback on the program. Mr. Tadahiro Umetsu of the Greenery Promotion Department of Sapporo City and Ms. Chisato Maki of the NPO Barato River Environmental Citizen's Forum participated in the programs at Ariake Elementary School as observers and in the annual review meeting. Their valuable comments on the programs etc. were used as a reference for my doctoral dissertation.

When publishing Chapter 2, where detailed educational material was discussed, in the academic journal, Associate Professor Tomohito Yamada at the Faculty of Engineering, Hokkaido University, gave me many suggestions on how to discuss our educational materials with contrast to the three-storages tank model. I was very encouraged by his endorsement of the significance of environmental education for children based on scientific knowledge. Teachers of elementary and junior high schools in the subject committees of environmental education in the association for school-education study in the Ishikari area experienced the experiments using my educational materials. They gave me their opinions on how to use it effectively in school classes. In the discussion in Chapter 3, Mr. Kai Takahashi, working as an elementary school teacher, a graduate student in Yamanaka Lab, provided crucial information for this dissertation about the importance of "prior learning" before children's observations and experiments in elementary school classes. He also gave me accurate information when participated in "*Yama no Gakko*".

Committee members, Professors Yasuhiro Yamanaka, Teiji Watanabe, and Associated Professor Junjiro Negishi of the Graduate School of Environmental Science, and Professor Ayumi Nojo of Iwamizawa Campus, Hokkaido University of Education, gave me crucial advice at the review of my doctoral dissertation. In particular, Professor Ayumi Nojo gave me valuable advice from a pedagogical perspective.

The decade from 2011 to 2020 was a time of great change in my public and private life. I almost gave up on my research many times. Thanks to all supporting me, I was able to complete my doctoral dissertation. My wife Uju and my daughter Tao supported me a lot mentally. I would like to express my heartfelt gratitude to my family.

Finally, I would like to express my gratitude to all of you once again.

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Chapter 1 General Introduction

1.1. Background of This Study

The 2020 Environmental White Paper states that we are now in an era that should be called "climate crisis" rather than "climate change," as weather-related serious disasters frequently occurred around the world and increased the risk of weather disasters caused by global warming. At the Sustainable Development Summit held at the United Nations Headquarters in New York in September 2015, the Sustainable Development Goals (SDGs), consisting of 17 interrelated goals and 169 targets, were adopted as the goals of the action plan for humans, earth, and prosperity, and Japan is actively working on them.

As the above shown in the environmental white paper, environmental problems are becoming more serious, diverse, and interconnected, and the achievement of the SDGs in individual regions is necessary to build a sustainable society in the whole country. Environmental education from childhood will be important to achieve the SDGs in the region. Japanese law defines "environmental education means education and learning about environmental conservation conducted to deepen understanding of environmental conservation" (Article 2, paragraph 3 of the Act on Promotion of Motivation and Environmental Education for Environmental Conservation). The 20th proposal of the Sub-committee relevant to environmental thought and education in Committee of Environment, Science Council of Japan states that the goal of environmental education is "to enrich the 'nature inside' of children, to help them understand the immeasurable blessings of the environment on humanity and how it works, to conserve the environment, to deepen their awareness of the interaction between humans and the environment, and to help them acquire the so-called 'environmental literacy' actually to improve the environment." While the part about "enriching the nature inside" of children requires a separate discussion, increasing the environmental literacy of children is desirable towards achieving the SDGs in their individual areas.

For environmental education in elementary schools, there is an emphasis on hands-on education using the body and simple tools to look at the environment around us (National Institute for Educational Policy Research Curriculum Research Center, 2014). In order for elementary schools to create opportunities for hands-on environmental education, not only by teachers, but also by requiring the understanding and cooperating of parents and community relevant organizations to prepare for out-of-school activities and instructors

(National Institute for Educational Policy Research, 2014). In order to create hands-on environmental education opportunities, elementary schools are required to prepare leaders and places for activities outside the school not only by teachers, but also by parents and other relevant institutions in the community with the understanding and cooperation (National Institute for Educational Policy Research, 2014). Inamori et al. (2009) also pointed out that environmental education in elementary schools requires collaboration with the outside, such as schools and non-profit organizations, companies, and government agencies.

Universities, as centers of learning, have an essential role in searching for truth deeply and in teaching and researching of "specialized arts and sciences" and a public role to play in the knowledge-based society of the future (Ministry of Education, Culture, Sports, Science and Technology, 2005). Universities could be a partner in environmental education in elementary schools. As a specific example of the collaboration, there is the "Hirameki☆Tokimeki Science" conducted by the Japan Society for the Promotion of Science (JSPS). These are the programs that researchers of universities and research institutes use cutting-edge research results to provide fifth- and sixth-grade students, junior high school students, and high school students with an opportunity to experience the fun of science by seeing, hearing and touching it firsthand. In fiscal year 2018, 278 programs were implemented and 90 were implemented for elementary school students.

In these case studies of collaboration, what do researchers studying natural science, not studying education, in universities pay attention to when they provide elementary school students with science knowledge and experience in their classes? In the "A guide to observations and experiments in elementary school science" (MEXT, 2011), prior learning is considered essential for children to have expectations and hypotheses with their own clarified purpose before observation and experiment. How do university researchers conduct its lessons with an awareness of what is considered necessary in elementary school classes? Such a simple question comes to mind.

1.2. An environmental education, elementary schools "*Yama no Gakko*," in collaboration with graduate school, companies

Groundwater was often treated as a local resource, such as land subsidence and groundwater pollution, but groundwater is part of the water cycle pathway, and groundwater research from a global perspective is important for understanding global environmental issues (Taniguchi, 2000). Access to safe water is one of the themes in the SDGs.

Since the course of study for elementary schools does not systematically deal with groundwater from the perspective of the water cycle, classes on groundwater are rarely given in elementary schools.

The "*Yama no Gakko*," the target of this doctoral dissertation, is an environmental education program for elementary school students to learn groundwater, which is a good case that university researcher has been developing in environmental education in elementary schools for several years. This activity is an environmental education to provide nature experience and environmental learning for upper graders of elementary schools in cooperation with a graduate school and a company, mainly in Mt. Shirahata in Kiyota-Ku, one of the largest water sources in Sapporo, Japan. This activity was started in 2013 for upper graders of the elementary school in Sapporo, and in 2015, based on a request from the Sapporo Ariake Elementary School, the activity has been carried out once a year for 5th and 6th graders of the school until now.

This activity collaborates between the Graduate School of Environmental Science, Hokkaido University, Hokkaido Coca-Cola Bottling Co., Limited, and General Incorporated Association Project Design Center.

Hokkaido Coca-Cola is conducting an afforestation at Mt. Shirahata in Kiyota-Ku, Sapporo, the water source of its plant, based on the "Environmental Business Agreement" signed with Sapporo City in June 2011. As one of the specific initiatives, an environmental education program is held every year for afforestation by elementary school children, entitled "Coca-Cola Mori ni Manabo Project (Learning from Forestry in Japanese)" (from Hokkaido Coca-Cola's website, https://www.hokkaido.ccbc.co.jp/comunication/growup.html). As a community-based company, this company has established a Public Relations and CSR Promotion Department. It is actively implementing environmental education activities such as afforestation for elementary school students and visiting classes on the theme of groundwater to foster the next generation. *Yama no Gakko* is done as one of those activities, and this company takes on the role of cost sharing and public relations.

The course in Practical Science for the Environment (PractiSE) was established in 2011 associated with the reorganization of the Graduate School of Environmental Science, Hokkaido University, a course developing human resources with expertise in environmental science and abilities to address problems in cooperating with various stakeholders. In 2014 FY, the Graduate School of Environmental Sciences and Hokkaido Coca-Cola have signed a cooperation agreement to cooperate in such as education/research exchange, human exchange, and information exchange in order to contribute to environmental conservation and the development of local communities in Hokkaido. Since then, the activities of *Yama no Gakko* have been led by researchers in the PractiSE based on this agreement. The program being implemented was developed by university researchers (Table 1).

Table1. Programs conducted in *Yama no Gakko*

Year/Month	Purpose	Overview	Location
2013.8	To feel the difference between day and night forest with our five senses	Observations of insects day and night, bats' habitat using a simple ultrasonic detector. Twenty-five children of 4-6 graders in elementary schools and their parents participated.	*Fureai no Mori* Forest
2013.9	To understand the significance of tree planting and planting Japanese water oak	Measuring the breast height of trees and the distance between trees and reproducing the three-dimensional forest structure using software simulating the growth of the forests. Thirty children of 4-6 graders in elementary school in Sapporo participated.	*Fureai no Mori* Forest
2014.1	To understand the entire water cycle	Role-playing game walking along the water cycle, and the experiment detecting mineral components in some sample water using reagents. Seventeen children of 4-6 graders in elementary schools in Sapporo and their parents participated.	Hokkaido University
2014.9	To understand the state of the river in the spring area	Observations of the water springing and aquatic insects using micro-scopes. Thirty-eight children of 4-6 graders in elementary school in Sapporo participated.	*Fureai no Mori* Forest
2015.6	To understand forests are one of the sources of groundwater recharge	Experiment using the educational material made of Lego® blocks, a sprinkling experiment onto forest ground and hard bare land, and observations of the forest using a drone. Twenty-six children in fifth and sixth graders of *Ariake* Elementary School participated.	*Ariake* elementary school, Coca-cola forest
2016.6	To understand how rain turns into clean groundwater	Experiment using the educational material made of Lego® blocks, and experiment on filtration using sand and pebbles. Twenty-four children in fifth and sixth grade in *Ariake* Elementary School participated.	*Ariake* elementary school
2017.7	To understand forest soil is easy to infiltrate groundwater	Experiment using the educational material made of Lego® blocks, a sprinkling experiment onto forest ground and hard bare land and observations of the underground soil and plant roots. Twenty-one children in fifth and sixth grades in *Ariake* Elementary School participated.	*Ariake* elementary school

2018.6	To understand forest soil is easy to infiltrate groundwater	Sprinkling experiment onto forest ground and hard bare land and observing the underground soil and plant roots. Twenty-one children in fifth and sixth grades in *Ariake* Elementary School participated.	Coca-cola forest

During seven years from 2013 to the present, the targets of this research are activities for four years from 2015 to 2018 implemented for 5th and 6th graders of Ariake Elementary School in Sapporo City when *Yama no Gakko* has implemented, are. The author was the coordinator of the tripartite collaborations and has participated in educational programs implemented from 2013 to 2018. Therefore, the author attended all meetings to implement the educational programs and documented how the researchers developed it.

1.3. Academic questions in this dissertation

This dissertation clarifies the role of a university researcher in the central role, overcomes the differences in teaching methods between graduate schools and elementary schools in *Yama no Gakko* implemented for several years, and discusses the key points for university researchers and other professionals when working with elementary schools.

First, this dissertation focused on an educational material developed by university researchers for use in the programs of *Yama no Gakko*. This educational material is made of materials that are inexpensive and available to anyone, and represents the principles of nature using the expertise of a natural scientist. Educational materials are important tools for helping children to reach class goals, as it defined by Ebitani et al "Educational material is a medium through which the mutual relationship between teacher and learner is established and through which learners can reach class and unit goals" (Ebitani et al., 1981). Therefore, the development of educational materials requires carefulness. For example, there is an educational material which two plastic bottles filled with air with different concentrations of carbon dioxide are illuminated by a light bulb, and the temperature of the gas inside the bottle with the higher concentration of carbon dioxide is observed to be higher than the other one, in order to arouse children's interest in the issue of global warming. There have been criticisms of this educational material, such as "As the device is not isolated, the effects of heat transfer such as conduction, convection, and radiation from the environment around the device are still present in large problems, making it difficult to describe global warming and inappropriate as an educational material"

(Serizawa et al., 2013). Even if the scientific backing is not directly understandable to children, any educational materials do not ignore scientific backing. Chapter 2 discusses how university researchers represented natural phenomena in this material in a scientifically credible manner to reach their course goals through quantitative examinations of the phenomena it represents. The author also improved the materials to help children better understand groundwater during the quantitative examinations. This improved educational material was later used in *Yama no Gakko*.

Then the educational programs, a specific way of learning, were also focused. The educational materials do not exist in isolation but are closely related to the way of learning, and teachers' attitudes toward learning are reflected in the educational materials (Morimoto, 2000). Chapter 3 discussed in detail the content of the programs and educational materials developed by him, an expert in the natural sciences but not in elementary education. He continued to offer a new program every year for four years, responding to requests from elementary schools while drawing on their expertise and strengths. One of the objectives of the target school, Sapporo Ariake Elementary School, is to "cultivate humanity in touch with nature." What are the characteristics of the programs that continued for four years with high assessments from elementary school teachers and that they have requested to continue in the future? Compared with the process of observations and experiments in elementary schools, this question was discussed to identify points requiring attention and improvement for the multi-year continuity of the programs. And this dissertation clarifies the caveats when university researchers participate in environmental educations in elementary schools.

Chapter 2 Developing an educational material of learning groundwater based on a tank model for upper-grade students in elementary schools

2.1. Introduction

To promote policies comprehensively for maintaining and restoring sound water cycle, BASIC LAW ON THE WATER CYCLE was enacted in July 2014. One of the aims of the law is the conservation of groundwater and spring water that is not protected by the current legal system on water resources. "The Basic Plan for Water Cycle" stated under the law as follows. In order to learn the importance of water and to acquire ideas and behaviors to carefully use water from childhood, primary schools, junior high schools and high schools shall provide education on water circulation according to the stage of development and promotion to create of supplementary educational materials about water circulation that can be utilized for school education in accordance with the course of study, Science (MEXT, 2017a). There are many cases of environmental education related to water. That is because water is one of the important elements supporting the natural environment of the earth, like air and soils. However, there are a lot fewer cases focusing on groundwater compared to those on river and lake water.

We introduce some cases that local residents and companies cooperate to put effort actively into groundwater conservation. In the middle basin of Shirakawa River flowing through the northern part of Kumamoto Prefecture, there are groundwater basins shared by neighboring municipalities and groundwater flowing regions over a wide area. Under the Kumamoto Prefecture Ordinance for Groundwater Conservation, groundwater is regarded as public water, and various projects such as human resource development and learning in a community related to groundwater conservation are conducted.

Mishima City in Shizuoka Prefecture, located at the base of Mt. Fuji, has started a project to conserve the groundwater recharge function of forests in cooperation with local residents, in order to conserve the spring water group, which is a precious property of the city.

In Misato Town, Akita Prefecture, with abundant spring water, the local junior high school science club has conducted surveys of water quality and habitat of freshwater fish in spring water, an endangered species designated in the IA category by the Ministry of the Environment and Akita Prefecture.

Regarding learning water resources and water circulation in elementary school education, the new course of study, science and social studies for elementary schools (MEXT, 2017a, 2017b) will be implemented from 2020, stipulates as follows. Fourth graders learn securing water source forests for the supply of drinking water in a social studies unit "Structure of modern society, work and life of people." In a science unit "Runoff processes of rainwater and characteristics of the ground surface," 4th graders learn how the flow of water changes under the inclination of the ground surface, how water infiltrates by the size of soil particles, and how natural disaster impacts on water flows. They also learn water evaporation and condensation in another science unit of "Weather situation." Fifth graders learn that forest resources play an important role in environmental preservation of land and water-source recharge, etc. in a social studies unit "Features of the geographical environment of the land in Japan and the current state of the industry, relationship between information society and industry". In a science unit "Flowing water's work", 5th graders learn flowing water's works, mode of rain, and runoff processes of rain. Six graders learn geologic layers formed by river in a science unit "Land formation and change". Furthermore, environmental studies are suggested to be suitable cross-curriculum and comprehensive exploration themes in a subject of "Period of integrated studies." As an example, there is a model case that a school addresses to learn abundant forests around the school area, and then provide learning activities of the environment, resource, industry, and etc. related to the forests.

As an educational material about groundwater designed for 5th and 6th graders, there is a water filtration device replicated the filtering function of groundwater. The device is a transparent container, in which gravel, sand, activated carbon, etc. are laid in layers. When muddy water is poured from the top of the device, transparent water is filtered out from the bottom of the device. We found similar devices as experimental educational materials provided by educational materials manufacturers (for example, products of Artec Co., Ltd.), and handmade educational materials using such as PET bottles on some websites (for example, "Laboratory on forest and water by Coca-Cola system"). Because most of the educational materials are made of natural resources such as gravel and sand, children can visually understand the soil layers and the detailed process of infiltration of groundwater. However, these materials do not help children to have a holistic image of groundwater system. In addition, the classroom gets messy by gravel and sand. There is another kind of an educational material demonstrating a water cycle: water drops slowly from melted ice fell onto the surface as rain, gathered in a basin, and reached to the sea through a river (for example, the product of Techno International Co., Ltd.). It includes representation of only rainfall and river (surface water) but not groundwater. In order to promote understanding of the entire water cycle, it is necessary to develop an educational material learning groundwater functions in the water cycle.

The purpose of this chapter is to develop an educational material for upper-grade students in elementary schools. They can learn the basic knowledge of groundwater and understand the role of forests, occupying 66% of Japan, as major recharge areas of groundwater. The structure of this educational material is based on the tank model with three storages. The tank model is a method for calculating the flow rate of a river from rainfall, suggested by Masami Sugawara at former National Research Center for Disaster Prevention (after the change National Research Institute for Earth Science and Disaster Resilience) (Sugawara, 1993).

Japan Meteorological Agency has adopted the three-storages tank model to obtain soil water index for the judgment of the sediment disaster risk (Japan Meteorological Agency).

Considering usability in the field of education, familiarity for children, and obtainability of materials, we used sponges and plastic blocks. We clarified the characteristics of the developed educational material such as the response and water balance to sprinkling water. We demonstrated the educational material to elementary school teachers and obtained their comments on the usages of it in school education.

As an aspect of the outreach of scientific knowledge, this chapter is intended for hydrology experts and elementary school teachers to read. Therefore, we wrote this article in plain descriptions by only referring to fundamental scientific knowledge, which could be insufficient for hydrology experts

2.2. Developed educational material

2.2.1. Objects represented by this material

The educational material developed in this study demonstrated the following two facts for upper-grade students in elementary schools to learn groundwater in relation to water resources and water cycle.

(1) Forests are major recharge areas of groundwater

We present the process that rain and snow falling to the forests infiltrate into the underground and become groundwater. By observing the process and understanding the role of forest, students can learn the function that the forests recharge groundwater from the ground surface through the afforestation activities. Moreover, they understand that forest conservation activities are meaningful for groundwater recharges.

(2) Groundwater residence time is longer than surface water residence time

The material also represents the process that groundwater flows slowly and its residence time is longer than surface water's time. By observing the process of groundwater recharge in the material, students can learn taking a long time to recharge groundwater and figure out why conservation activities require taking for a long period of time.

2.2.2. Three-storages tank model developed in this study

The tank model is a model for calculating the amount of river flow from rainfall. Rain is gathered into the top tank and also evaporated away from the top tank. Each tank has an outflow hole on the side and infiltration hole at the bottom. The water in each tank flows out from the outflow hole or moves from the infiltration hole to the lower tank. The vertically layered stepwise structure of the tank corresponds to the multi-layered structure of aquifer (Sugawara, 1985). Japan Meteorological Agency uses this three storages tank model for sediment disaster prediction. This is because it is possible to predict the amount of river runoff caused by rainfall by tuning appropriate parameters, the number of tanks, the height of the outflow hole, the coefficient of run-off and the coefficient of permeability etc., to the actual situation. In the model of the Japan Meteorological Agency, the outflow from the outflow hole on the side of the first tank corresponds to the surface runoff, the outflow from the second tank corresponds to the infiltration outflow from the surface layer, the outflow from the third tank corresponds to the outflow as groundwater (Figure 1). In this material, we did not create the infiltration system from the third tank into the further deeper layer.

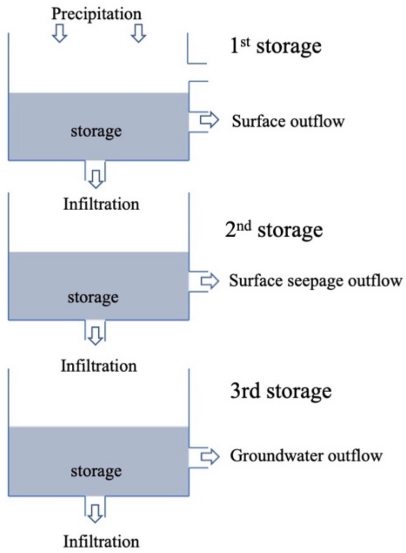


Fig.1 The structure of three-storages tank model

2.2.3. The structure of the educational material in this study

We used two kinds of sponges in the groundwater aquifer of this educational material. One is melamine resin sponge and the other is foamed phenolic resin sponge, those have different water permeability. These sponges are easy for everybody to obtain. We used the Lego® blocks in plastic blocks for the frame. Lego® blocks is familiar to children. They can easily assemble and disassemble blocks to imitate the physical structure of topography of land because the shape and size of the parts are abundant. It is easy to visualize the underground layered aquifer system compared with the materials using real sand, gravel, soil, etc. The blocks are easy and clean to handle in classrooms. To be assembled with familiar materials, we obtained all available materials used in this educational material (except Lego® blocks) at 100-yen shop, in which most of goods are available at the price of 100 yen. Other materials assembled for the educational material are easily obtainable and mostly available at 100-yen shops.

The educational material covers the basin as a basic unit in the water circulation. The vertical structure of this educational material is referred to the 3-storages tank model. The first tank represents a ground surface including the river, the second tank represents a surface layer of soil (hereinafter referred to as the surface layer), and the third tank represents an aquifer. This educational material represents an entire basin as one three-storages tank, although the model of the Japan Meteorological Agency has one three-storages tank for each gird of 5 km square. In order to simplify our model, we decided to skip the process that surface water and groundwater in the upstream area flow up to the ground surface and the bottom of the river. As a result, we're able to measure the outflow of the whole area from each layer. We conducted another experiment to clarify the long-termed characteristics of groundwater in the third tank. The horizontal layout of the material surface was made by simulating the actual topography with Lego® blocks. The river was placed in the centerline from the upstream area to the downstream area, forming an alluvial fan with forest, farmland, urban area, etc. This was the structure of a typical alluvial fan including Sapporo city.

Each plastic wrap film laid between layers is impermeable. For the area covered by forest and farmland areas, water need to be infiltrated into the soil. Therefore, we made small holes in the films and gaps between Lego® blocks for the infiltration. The surface and groundwater layers had different permeability. The groundwater layer had a longer passage distance filled by the foamed phenolic and melamine resin sponges more than the surface layer. The foamed phenolic resin sponge had low water permeability and high-water retention capacity (The amount of melamine sponge was about 821 cm^3 in the surface layer, about 1,306 cm^3 in the underground water layer, and foamed phenol placement amount of resin sponge was total 1,328 cm^3 in both layers). We confirmed the water permeability and the residence time of water in other experiments using sponges. Details will be described later. In the groundwater layer, the water flow was meandered by Lego® blocks, in addition to select sponge with long residence time, in order to delay outflow from the groundwater layer (Fig.2). The response characteristics of the groundwater layer in this educational material were determined by the type and amount of sponge and the shape of water flow paths above.

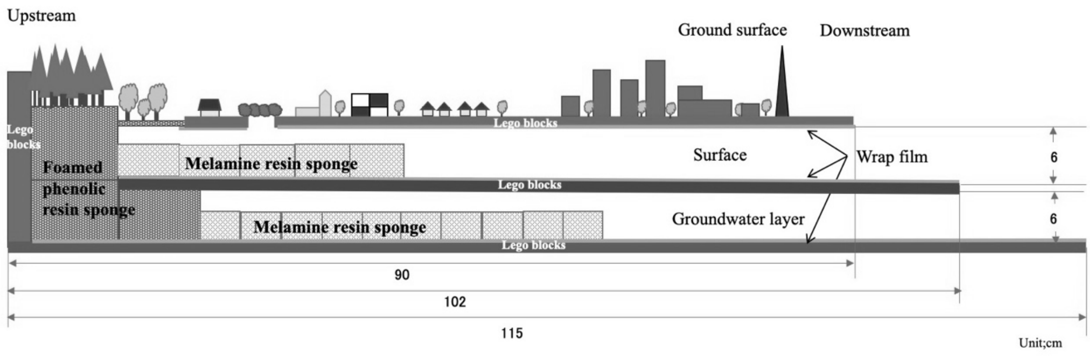


Fig. 2 Structure of educational material

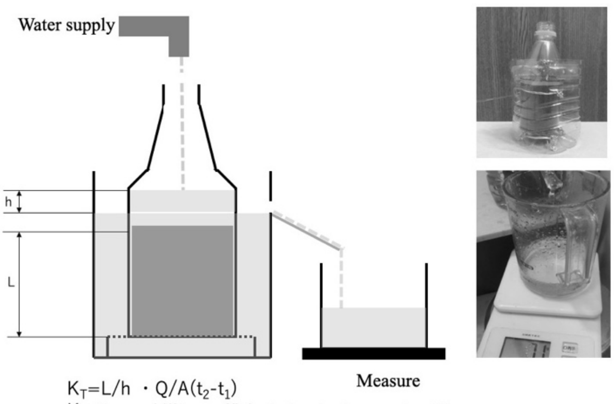
In the experiment, the educational material was inclined from the upstream side to the downstream side. The educational material can be used with any inclination. In this experiment, we set the inclination of the educational material to 1/20, because we needed the optimal time for students to make a good balance of leading step-by-step understandings by slow water flow and keeping their attention to the material. This inclination is about twice of the river inclination of the uppermost stream of the Toyohira River, and about 5 times of the hydraulic gradient of the typical alluvial fan in Japan.

Water sprinkled to the upstream part gathers in the central part of the river through streams and sewers on the ground surface and flows out of the device from the most downstream part. Some of the sprinkled water infiltrates from the forest and farmland into the surface and the groundwater layers. Groundwater is stored in sponges simulating an aquifer and flows out of the educational material from the most downstream part. This educational material does not represent the evapotranspiration, the infiltration of river water into groundwater, and the discharge of groundwater from the riverbed.

2.3. The sprinkling experiment on this material

2.3.1. Preliminary experiment for measuring the permeability of the sponge

We measured how much water passed through the two types of sponges used in this educational material compared to natural materials such as clay, sand, and gravel, as a primary experiment. We conducted a constant head permeability test, a permeability test of soil determined by General Building Research Corporation of Japan, and obtained the permeability value of two types sponges: melamine resin sponge installed in the surface layer and foamed phenol installed in the underground water layer. All materials used in the experiment are easy to obtain. We used two types of bottles cut to a suitable length. One is a large PET bottle for drinking water (2ℓ size) and the other is a PET bottle for carbonated water (500 mℓ size), We also used a kitchen drainage net for fixing the specimen sponge and a wire for fixing the inner bottle containing the sponge to the outer bottle.



$K_T = L/h \cdot Q/A(t_2 - t_1)$
K_T: Permeability coefficient at water temperature T
H: Water level difference, cm
Q: Permeability, cm^3
$t_2 - t_1$: Elapsed time
A: Section area of sponge, cm^2
L: Length of sponge, cm

Fig.3 Experimental device for water permeability test

Although this experimental device is structurally similar to the educational material of water filtration introduced in the Introduction, which is to demonstrate the filtration function of groundwater on increasing water transparency this device measures the amount of water that passes through the sponge. In the experiment, water was supplied directly from the tap in order to be stabilize the water level in the experimental device. We weighed the mass of the effluent water on a cooking scale (scale unit: 1 gram) and converted it to water volume as 1 g = 1 cc. These sponges were saturated (water content of each sponge was maximum) at the start of measurement, and we measured three times for each of the two types of sponge. The experiment showed that the mean value and the standard deviation of the permeability coefficient of the melamine resin sponge and the foamed phenol resin sponge were 0.77 ± 0.02 cm/sec and 0.069 ± 0.002 cm/sec, respectively. In the same experiment, those of the river sand were 0.21 ± 0.06 cm/sec.

In this experiment, it was confirmed that the permeability coefficient of the sponge used in this study was the same value as the permeability coefficient of sand and gravel obtained in the previous study (Fig. 4).

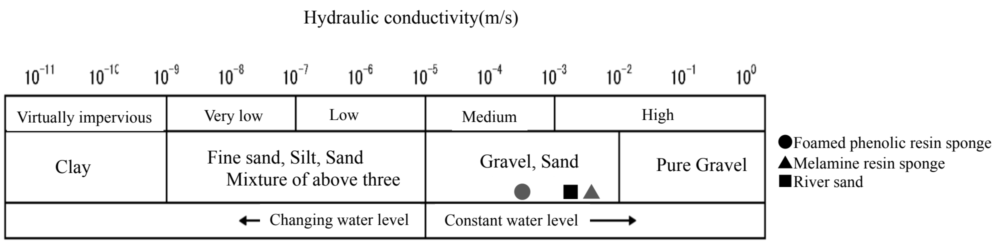


Fig.4 Applicability of water permeability and test method

2.3.2. The method of sprinkling experiments

In order to prove whether this educational material is effective for teaching the basic knowledge of groundwater, we conducted a sprinkling experiment and obtained water balance such as response characteristics to sprinkling.

In the experiment, we sprinkled water on the forest part of the educational material (in the coordinates A1, A2, B1 and C1 of Fig.5) and measured the mass of water flowing out of the three layers for 3 minutes. Every 3 minutes, we sprinkled 500cc water with a hand-held watering pot for about 20 seconds and repeated it 18 times. We conducted this sprinkling by hand as the same situation in elementary schools, in spite of reduced reproducibility of experimental results. Although the reproducibility of experimental results might be reduced, we sprinkled water by hand considering the situation of students' use. At the end of the downstream of each layer on the ground surface, surface layer, and groundwater layer, we set up a plastic tray for receiving each outflowing water and a digital weighing scale (measurement resolution 1 g) for measuring the mass of water. We recorded the value displayed on the digital weighing scale, read each mass of the outflowing water every 2 seconds, and converted it to each amount of water as 1 g = 1 cc. The mass differences between the water-contained sponges after the experiment and the dry sponges in the surface and groundwater layer were the total amount of reservoir water stored in each layer. surface layer and the groundwater layer. In order to prevent water leakage from the side and bottom of the educational material, we closed the gaps between blocks with tapes, and there was almost no water leakage out of the device. The amount of water calculated from the water balance was regarded as the residual water accumulated between protrusions of the blocks and dents of the wrap film.

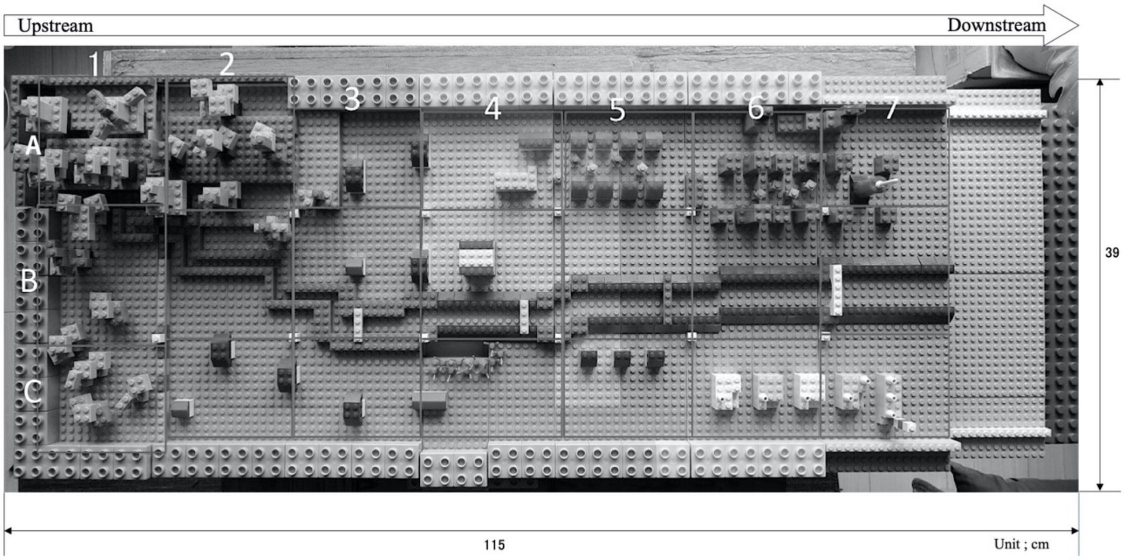


Fig. 5 Plain view of educational material

2.3.3. The results of sprinkling experiments

(1) The total water balances

We sprinkled a total of 9,000 cc water in 18 experiments (Figure 6). As a result, 76% of the total was flowed out from the sponge, 23% was absorbed by the sponge, and 1% was stored in the material. Since the amount of residual water is calculated from the residual of water balance, it may include errors of measurement or unintended water leaks from the gaps between blocks, etc.

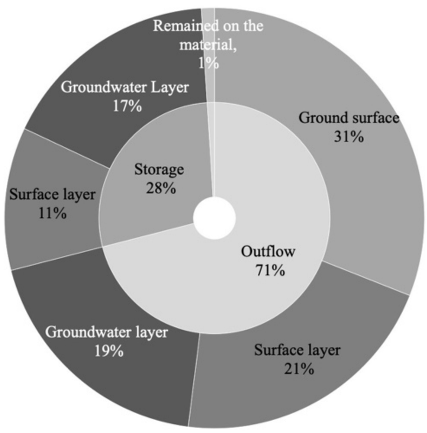


Fig. 6 Total water balance for 18 sprinklings

(2) Time sequences of water balance

In 18 experiments, the amount of water outflow has gradually increased after the first sprinkling. The water amount of inflows and outflows became almost the same in the 15thsprinkling, and thereafter the flows had been kept in a steady-state. From the first sprinkling, the outflow of water has begun on the ground surface. As being flowed out some, water was stored little by little in the dents on the wrap film laid under the ground surface and in the protrusions of the blocks, and then the flows had been kept in a steady-state from12th sprinkling. In the surface layer, the outflow of water started from the 2nd sprinkling and stabilized at about the 8th sprinkling. In the groundwater layer, the outflow of water started from the 6th sprinkling and stabilized at about the 15th sprinkling. (Figure 7).

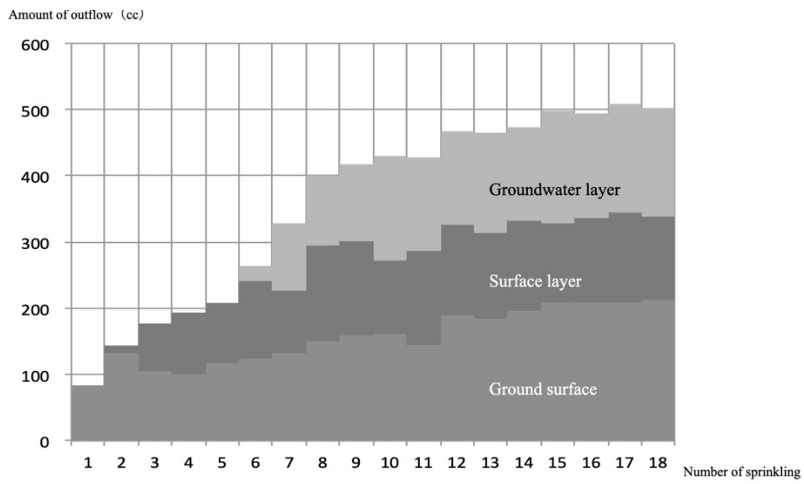


Fig. 7 Outflow amount from three layers for each sprinkling

The differences beginning and stabilized times of outflows between the surface and ground layers is due to the differences of the permeability coefficient and the amount of sponges installed in these layers. The reasons for making the differences of ways to flow out and numbers of becoming in steady-state were due to the different permeability coefficient and total amount of sponges installed in surface and ground layers.

Although there was no sponge used on the ground surface, it took 12 times of sprinkling water to stabilize water outflow due to filling out the dents of warp films with water first.

(3) Time sequences of outflows and water balance after stabilized by sprinklings

The outflow volumes were averaged by described above, are shown in Fig. 8. Because water outflow had been stabilized after 15th sprinklings as described above, the outflow volumes were averaged by the results of four sprinklings from 15th to 18th. The outflow volumes are shown in Fig.8

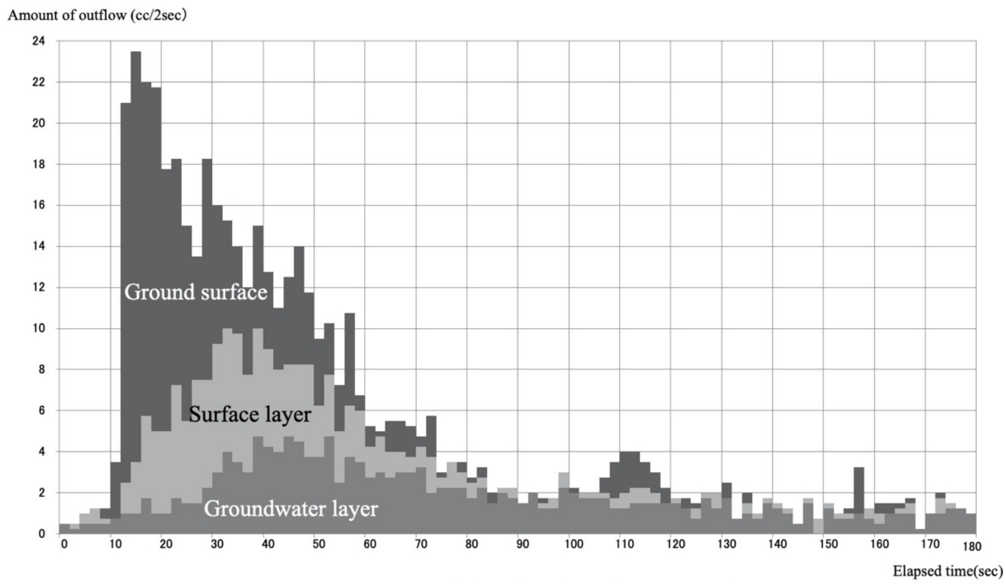


Fig.8 Outflow amount on average in stable state

From the ground surface, the amount of outflow water hit the peak around 16 seconds after the start of sprinkling and started to decrease. Then, the outflow was stopped almost after 90 seconds of the peak. Small peaks appeared after a sharp peak were occasionally caused by the outflow of water drops left by surface tension on the device. From the surface layer, the outflow water hit the peak around 32 seconds after the start of sprinkling. After the peak, the amount of outflow water had decreased gradually until the last measurement in 180 seconds. From the groundwater layer, the outflow water generally hit a gentle peak around 40 seconds after the start of sprinkling and then gradually decreased, and a small amount of outflow continued until the end of the measurement.

(4) Residence time of water in the groundwater layer

The water content in the sponges installed in the groundwater layer was 1,438 cc, and the averaged outflow for each sprinkling averaged in a stable state, after the 15^{th} sprinkling, was 164 cc, the residence time in the sponges (= 1,438 cc / 164 cc) was 8.8 times. Like the ground water, there might be some spots on the sponges where water would be quickly replaced. Therefore, until all water in the sponges was completely replaced, we also measured the residence time using a simple device. In this measure, the ground layer was taken from the original educational material, under the same conditions such as the amount of sponges and its inclination (1/20). The sponges were saturated with tap water in advance. In each time, we sprinkled saltwater (electrical conductivity: 0.8 s / m) onto the sponge which placed on the upstream for approximately 36 seconds and measured the electrical conductivity of the water flowing out from the downstream of the sponge for 1 minute from the start of sprinkling. We repeated the process for 23 times.

The amount of sprinkled saltwater was 160 cc for each time. The amount of outflow from the groundwater layer in the experiment using the educational material was almost the same as 164 cc.

The electrical conductivity of the outflow increased almost linearly with the sprinkling times and reached 0.8 s / m at the 21th sprinkling accumulated about 3,400 cc (Figure 9). At this time, the water inside the sponge was considered as being completely replaced by the initial state. If the water newly infiltrating into the sponge pushed out the old water in order, the water in the sponge would be perfectly replaced during the residence time. However, in fact, both fresh and old water got mixed in the sponge and the mixed water was flowed out. If mixed water flowed out from the sponge, the residual amount of water decreased exponentially by 1 / *e* (= about 37%, where *e* is the base of natural logarithms) per residence time, and decreased to 9% at 21times (2.4 times the residence time). The result from this experiment was closer to the number decreasing exponentially with mixing fresh and old water than the number decreasing rapidly with pushing out old water by freshwater, which was estimated as 8.8 times. From the results, we found that fresh and old water flowed out with mixing together in the sponge.

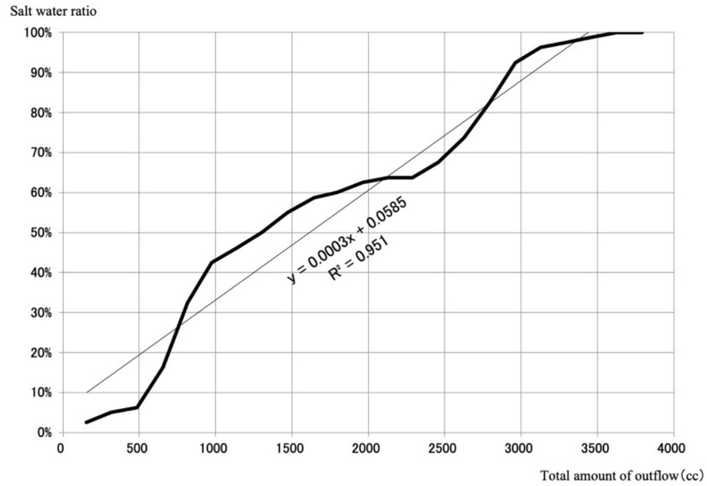


Fig. 9 Ratio of saltwater to accumulated water outflow in the experiment of exchange of saltwater for freshwater in the aquifer

2.4. Interview to school teachers

On July 26, 2016, we demonstrated a sprinkling experiment using the educational material to elementary and junior high school teachers in Sapporo City and the suburbs and received questionnaires with their comments on the material using in school education. On June 6th, 2016, we also conducted a class about afforestation and groundwater using this educational material as a "Period of Integrated Study" for 5^{th} and 6^{th} graders at Sapporo Ariake Elementary School. We interviewed three teachers after the class.

2.4.1. Target of survey

We conducted a survey for eight elementary and two junior high school teachers who belong to the subject committees of environmental education in the society for school-education study in Ishikari area, Hokkaido (hereinafter referred to as Sekikyo-ken). Sekikyo-ken established in 1966 is an independent research group organized by approximately 2,400 elementary and junior high school teachers in Ishikari area, and its purpose is to improve their skills through training and research activities. It has 19 expert committees and 13 subject committees, and the environmental education committee is one of the subject committees.

2.4.2. Method of survey

First, we explained the appearance and structure of the educational material as well as the flows of surface water and groundwater simulated by the educational material, and then we conducted a sprinkling experiment. We sprinkled water on the forest area in the educational material, and the teachers observed the outflows of water from three layers. In the questionnaire related to the 3 storage-tank model, we described water in the first tank as surface water, water in the second tank as shallow groundwater, and the third tank water as deep groundwater. After conducting the experiment, we exchanged opinions for about 30 minutes, distributed the questionnaire, and asked them for filling out.

2.4.3. Item of questionnaire

The questionnaire consists of 13 questions totally, 3-page A4 papers, asking the following 5 points (including the others).

(1) The understanding level of teachers: How well do they understand the function of forests and farmland as recharge areas of groundwater and the differences of the flow speed (residence time) between the surface outflow from the first tank, the infiltration outflow from the second tank, and the groundwater outflow from the third tank.

(2) The understanding level of the 5^{th} and the 6^{th} graders in elementary schools: How well do they understand the function of forests and farmland and the difference of the flow speed (residence time) shown as 1)? What should be done to increase the level of their understanding?

(3) Opportunity to use this educational material: How can teachers use this educational material in school education, and what kind of support will be necessary to use this material ?

(4) Improvement of the educational material: How well do teachers/children understand scientific knowledge and the material contents?

(5) Others:

A free description of their opinions and impressions including comments on exchanged ideas

2.4.4. Results of surveys and discussions

(1) The understanding level of teachers

Eight teachers answered that they could understand "forests and farmland are recharge areas of groundwater" and "the flow speed (residence time) of surface water, shallow groundwater, and deep groundwater are different from each other". Most of the teachers commented as "I was impressed to see the gradual outflow of underground water after a time lag from sprinkling of water." The points that were relatively difficult for them to understand were commented as follows. "It was difficult to image nature such as soil or forest with artificial Lego® blocks", "It requires basic knowledge of the structure of the underground stratum", and "There were technical terms in your explanation", etc.

Unit : Person

	Understandable	Almost Understandable	Neither	Not much	Can not understand
Forests and farmland are groundwater recharge areas	8	2	0	0	0
Difference in residence time of surface water, shallow water and deep water	8	2	0	0	0

Table 1: Answers by teachers to the questions about their understanding

(2) The understanding level of the 5th and the 6th graders in elementary schools

With regard to the children's understanding for the same question to teachers, four teachers answered "neither" for understanding of "forests and farmland are recharge areas of groundwater", two teachers answered "neither" or "do not understand much" for understanding of "the difference of flow speed (residence time) between surface water, shallow water, and deep water" (Table 2). The reason why they answered "neither" is that all ground surfaces of the educational material replicated by only Lego® blocks, so it is difficult to feel the different types of land-use by its color alone. Another reason might be the size of the material. When they demonstrate in the classroom with a large number of students, there might be not enough space to get close to see the differences of outflow times between three layers for all students.

Six teachers suggested that it can be more effective for students to understand the concept of this educational material, especially when they use it during the tree planting activities.

Unit : Person

	Understandable	Almost Understandable	Neither	Not much	Can not understand
Forests and farmland are groundwater recharge areas	2	4	4	0	0
Difference in residence time of surface water, shallow water and deep water	5	3	1	1	0

Table 2: Answers by teachers to the questions about children's understanding

(3) Opportunity to use this material

Six teachers answered that there are opportunities to use this educational material in elementary school education. (Three other teachers answered that there was no opportunity, and one did not answer.)

The teachers mentioned that there are opportunities for using this educational material in schools such as picking up the fallen leaves in the Home Economics of the 1st grade, learning of the river in the Science for the 3rd grade, agriculture, and farmland in the Social Studies for the 5th grade, learning of the stratum in the Science for the 6th grade, and environment in the Period for Integrated studies. Although there is no opportunity to directly teach groundwater based on the current course of study, the Period of integrated studies (MEXT, 2017c), the teachers suggested that this educational material can be more supportive to teach the above-mentioned subjects in classes. Four teachers answered that they could assemble this material by themselves and use it in their classes or other opportunities (other five denied to use it in their classes and one did not answer for this question). For the other question, eight teachers preferred to invite an expert to offer lecturers for students.

(4) Other comments

The answers to the question as to what kind of material was preferable were as follows. Not only "easily handled materials" (eight teachers chose for multiple answers), "familiar materials" (two teachers), "materials not making the classroom dirty" (two teachers), which are what we intended, but also there were "realistic materials such as gravel and sand" (five teachers) and "specialized materials that are easy to understand" (three teachers). While the most of teachers evaluated the material positively because of its characteristics as easy-handling, familiarity, and tidiness, some teachers also indicated that it might be difficult to feel and understand natural environment from sponges and Lego® blocks. The answers to the question that explains "the ease of understanding based on scientific knowledge", which is the development intention of this educational material, include those such as "set the scientific knowledge top priority with a lower priority in understandability for children" (three teachers)," prioritize scientific knowledge to some extent with an increased priority in understandability "(seven teachers). No one chose "give priority to understandability without prioritizing scientific knowledge" and "Others".

In the interview survey, there were also opinions that "it is difficult to find an exit of groundwater, so it is necessary to make it visible by extending the flow path, etc.", and " this educational material is very good to understand the significance of afforestation deeply when provided together with actual afforestation activities.

2.5. Discussion

We discuss whether children in 5th and 6th grade can understand "the forest is a major recharge area of groundwater" and "groundwater has a longer residence time compared to surface water" by using this educational material.

About 70% of the water sprinkled on the forest area infiltrated into the underground in this educational material (Figure 6). In this study, the rate of underground infiltration became higher than the known values because we focused on the groundwater. The higher rate helped the school teachers to understand that the forest was a recharge area for groundwater, shown by the results of their interviews.

In this educational material, we divided the geologic stratum into a rainfall-sensitive surface layer and groundwater layer (rainfall-insensitive layer). The lag times between the timing of sprinkling to the peak of the outflow from both underground layers are longer compared to those for surface runoff, which was attributable to high water retention capacity of sponges and longer paths of water formed by the complicated spatial placements of the sponges. High variability of outflow rates between underground layers was generated by installing a larger amount of melamine resin sponge and foamed phenolic resin sponge with a low coefficient of permeability in one over the other. The lag times between the start of sprinkling to the peak of the outflow were 16 seconds, 32 seconds, and 40 seconds for the ground surface, surface layer, and groundwater layers, respectively. Regarding the time scale for the lag time between rainfall and river runoff responses, flow rates in Atsubetsu River and Tsukisamu River basins in Sapporo city had increased for one to five hours after local heavy rainfall (Yonemori et al., 2015).

The observed lag time between the start of sprinklings and the peak of outflow varied among layers in the educational material. It was a good representation of the processes where runoff comprises of the basal outflow component flowing out over long duration and quick outflow component flowing out to the river in a short time -flow. An observation of unpressurized groundwater, which often happened in the shallow layer, has being carried out at the observation wells of unpressurized groundwater level in Bannaguro, Ishikari City located north of Sapporo City. This long-term observation program records monthly averaged water level. According to this program, the groundwater level starts to rise at the start of snow melting, and there is no big-time difference between the day disappearing snow and the day having the maximum groundwater level (Fukami, 2011). Pressurized groundwater that often exists in deep layers was found in the 400-m deep underground wells at a beverage maker in Sapporo city had passed for over 70 years after precipitation (Matsubara et al., 2015). If our experimental material fits into the context, the different time lags of water flow from sprinkling to outflow between the surface layer and the groundwater layer could be regarded as the time lags of the precipitation between the unpressured groundwater and the pressurized groundwater.

Although it is necessary to consider the scaling rule when comparing this educational material with actual processes in the Toyohira River, we could give the following qualitative explanation to children about the time to reach the outflow peak. For example, if we converted 10 seconds in this educational material into actual one hour, the outflow of surface water in nature took several hours longer than it in this educational material. I can qualitatively explain to students that the river water will rise several hours later after the local heavy rainfall. If we regarded sprinkling water with intervals of 180 seconds as snow melting event recurring once every year, we would qualitatively explain to students the annual change of unpressurized groundwater level. The amount of outflow from the groundwater layer would not the same unless sprinkling were repeated at intervals of 40 seconds or less because of the outflow peaks after sprinkling in 40 seconds. As it is practically difficult to maintain such continuous sprinkling in a short period of time, this educational material would not be suitable to be used in explaining the stable water level of the confined groundwater on a long-term scale.

This educational material represents a three-storages tank model in which precipitation flows to the river through surface water and groundwater, and we can use the lowest compartment (underground layer) to explain properties of longer-term groundwater. In the experiment to saturate the sponges replicating the third storage with tap water and pour saltwater, the salinity of the outflow water gradually increased, and the water in the sponges was completely replaced with saltwater after 21 times of sprinkling. For example, if we convert one sprinkling into one year, we can explain to students that groundwater will stay there for a maximum of 21 years. Even if sprinkling is stopped on the assumption of climate change leading unexpected precipitation and groundwater recharge, the groundwater would continue to remain in the educational material. It is possible to pump up and use groundwater for a while, but it will soon be depleted. We would teach the concept of such "fossil water".

Although an experiment using the concept of electrical conductivity is advanced to the high grade of elementary school, it seems to be not very difficult to understand by using the term as salt concentration. A very small amount of inert ingredient and gas dissolved in groundwater are considered to hold information about the origin of the groundwater and the flow environment and used for a great deal of hydrology research to elucidate groundwater flow, water balance, origin, and age, etc. as tracers. (Kazahaya, 2007)
This experiment, using saltwater as a tracer, could show students that groundwater conservation requires a long-term perspective.

In this material, deep groundwater was completely replaced in 21 times by about 40% of sprinkled water. If we sought a more realistic situation, more sprinkling times would be required for complete replacement, because the percentage of sprinkling in this device into groundwater was more than that of precipitation in reality. For example, Matsubara and Negishi (2015) indicated that the groundwater of the Shirahatayama water system has been accumulated over 70 years old after precipitation. If we regarded one water sprinkling as duration of about 4 years, we could make more realistic explanation to children.

In the interview with teachers after the demonstration, we confirmed that they understood our intention of developing the educational material, especially based on scientific knowledge (the experimental results have been studied academically). The teachers understood the two functions demonstrated by this educational material: “Forests are a major groundwater recharge area.” and “Groundwater has a longer residence time than surface water.” We found that students would understand these functions, if this educational material was combined with tree planting activities.

2.6. Conclusions

For the conservation of groundwater, it is very important to create an opportunity for children to learn groundwater in elementary school education and to develop their attitudes to raise awareness of groundwater and conserve it. In this study, we developed an educational material using Lego blocks for 5^{th} and 6^{th} graders to understand “forests are the main groundwater recharge area.” and “groundwater has a longer residence time than surface water.”. In the sprinkling experiment, we were able to demonstrate that the forest is a groundwater recharge area by infiltrating water into the forest part of the educational material.

The time required to reach the outflow peak from sprinkling became longer in the order of the 1st, 2nd, and 3rd stages, replicating the ground surface, surface layer, and groundwater layer, respectively. As a result, the educational material represented that the influences of the ground surface by rainfall and snowmelt would be spread to river water, surface water, and groundwater placing in order of time. In the experiment, the sponge of a simple device imitating the third groundwater layer (aquifer) in the educational material was saturated with tap water and saltwater was sprinkled. Through the experiment, we were able to prove that groundwater had taken residence time for years. Because we had to sprinkle water over and over until water inside of the sponge was completely replaced by saltwater.

In the interview of teachers, they mentioned that they could generally understand the above two purposes of the experiment. However, in order to support for 5^{th} and 6^{th} graders learning underground functions, we should make some improvements such as distinguishing between forests, farmland, and urban areas, etc. to understand easily and increasing the size of educational material to make it easier for everyone to see when using this educational material in the classroom. We received an evaluation that children understand the significance of water cycle and tree planting more by using this educational material in conjunction with actual tree planting activities.

This study focused on the development of educational material. We would develop the educational program using this educational material in accordance with school courses based on the Courses of Study.

Chapter3 Characteristics of the environmental education programs for elementary school students developed by university researcher

3.1. Background

3.1.1. Environmental education for elementary school students by university teachers

University researchers studying the natural sciences are expected to provide elementary school students with opportunities for science knowledge and experience in the form of "*Demae* lecture" (university teachers going to elementary or high schools to have a lecture). Each year, numerous university researchers provide such opportunities. For example, in the "Hirameki☆Tokimeki Science" program run by the Japan Society for the Promotion of Science (JSPS), researchers of universities and research institutes use cutting-edge research results to provide fifth and sixth grade students, junior high school students, and high school students with an opportunity to experience the fun of science. In the fiscal year 2018, 278 programs were implemented and 90 were implemented for elementary school students.

Article 7 of Chapter II of the Basic Act on Education and Article 83 of Chapter IX of the School Education Act require universities, as centers of learning, to contribute to the development of society by providing the results through specialized education and research. In particular, graduate schools are educational and research institutions that build on advanced knowledge to acquire further knowledge, scientific views, and ideas through thesis writing (Ministry of Education, Culture, Sports, Science and Technology, 2018). Therefore, when university faculty members, especially graduate faculty members, work with elementary schools to provide environmental education, they cannot teach graduate expertise to elementary school students as it is. In addition, unlike middle and high schools, primary schools are taught by teachers who have studied in specialized teaching courses from undergraduate schools in universities, and university teachers are not well versed in teaching methods in primary schools. Therefore, it seems there are numerous challenges for university teachers to teach in elementary schools.

When universities collaborate on environmental education in primary schools, we need to identify what role is university researchers take on, how they are overcoming the challenges, what further challenges remain, and what improvements are necessary to make them better.

This chapter reports the activity of "*Yama no Gakko*," an environmental education program. This is an activity that provides learning programs about nature experience and the environment for children in high grades of elementary schools in collaboration with the company and the graduate school around Mt. Shirahatayama area located in Kiyota-ku, Sapporo, as the main field. The dissertation focuses on the role played by university researchers in their activities and discusses the characteristics of the materials and programs developed, the way of overcoming their challenges in the implementation, and the remaining challenges.

3.1.2. Observational and Experimental Learning in Primary School Science and Natural Science Paper Format

In the "elementary school observation and experiment studies" (MEXT, 2011), children develop an awareness of the problem in natural events, make predictions, and plan experiments before their observation and experiment studies. After the implementation, children organize the results of the experiment, test their predictions, and come to conclusions. Through this way in experimental and observational learning, children meet several stages before and afterward to clarify and reflect on problems and expectations (Figure 1). In particular, "Since the observation and experiment is an important part of science learning, the activity should not be aimlessly carried out. The observation and experiment become deliberate and purposeful activities and has a meaning and value only when the students have a clear objective, organize the results into tables and graphs, and reflect on them. In other words, as the guide states "The learning activities before and after the observation and experiment make the position of the observation and experiment clear", it is strongly pointed out that the children should have a clear purpose through prior learning (MEXT, 2011).

As discussed later, there is a form of logical construction used in university research called IMRaD. This is similar to the elementary school observation and experiment described above.

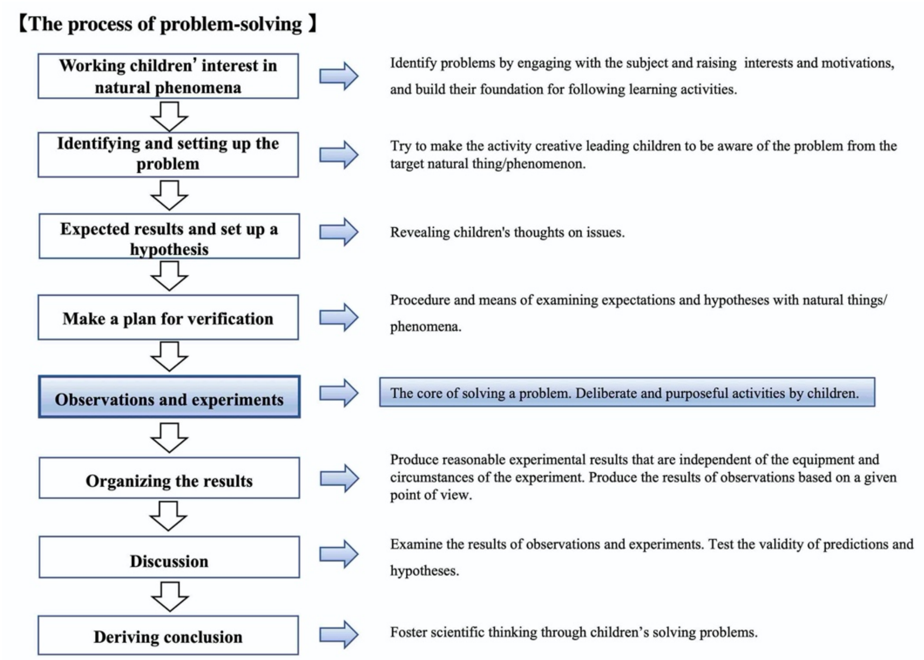


Fig.1 The order of the scientific observation and experiments (Source: Guide to Observations and Experiments in Elementary School Science (Ministry of Education, Culture, Sports, Science and Technology, 2011))

3.1.3. Development of educational materials by outside experts of primary schools

As examples of the materials for observations and experiments developed by experts outside elementary schools, there are the trunk kits developed by museum curators. When trunk kits are used with curators' lectures at elementary schools, etc., they are highly appreciated by the schools. Mitsuhashi et al. (2011) pointed out that elementary school teachers lack the knowledge and teaching skills to use trunk kits in their classes because more than 70% of elementary school teachers answered the need of outside experts with specialized knowledge for science educations in the Status Survey Report 2010 of Science Education at Elementary School (MEXT, 2010). At present, trunk kits would not be very actively used, as the museums are 5.2% often and 31.3% sometimes for often lending materials and book, according to the "Report on the Comprehensive Survey of Museums in Japan" (Japan Association of Museums, 2017).

Therefore, the case of the trunk kits shows that, even if the educational materials were designed to be used in elementary schools, it is necessary for the outside experts (in the case of the trunk kits, museum curators) to go to elementary school and use them, or to convey the specialized knowledge with those educational materials to the elementary school teachers in advance.

3.2. Target of research

3.2.1. Target of research

Yama no Gakko is an educational program that aims to preserve forests implemented by the Hokkaido University Graduate School of Environmental Science in collaboration with Hokkaido Coca-Cola Bottling Co., Limited at Mt.Shirahata located in Ariake, Kiyota-Ku, Sapporo. The main focus of this dissertation is an approximately half-day educational program conducted from 2013 to 2018 for upper grades at Ariake Elementary School in Sapporo (details are presented in section 3). We have obtained answers to the questions raised in 1.1 by investigating *Yama no Gakko* a professor at the Hokkaido University Graduate School of Environmental Science who is proactively implementing educational programs for elementary school students.

Hokkaido Coca-Cola, a member of this activity, is planting trees at Mt. Shirahata in Kiyota-Ku, Sapporo, where is the water source of its plant, based on the "Environmental Business Agreement" signed with Sapporo City in June 2011. As one of the specific initiatives, an environmental education program is held every year for planting trees by elementary school children, entitled "Coca-Cola Mori ni Manabo Project "Coca-Cola Project: Learning from Forestry in Japanese" (from the company's website).

The course in Practical Science for the Environment (PractiSE) was established in 2011 associated with the reorganization of the Graduate School of Environmental Science of Hokkaido University, a course developing human resources with expertise in environmental science and abilities to address problems in cooperating with various stakeholders. The associate Professor taking charge of the Graduate School of Environmental Sciences, who teaches making and implementation of programs in *Yama no Gakko*, is a researcher specializing in river benthic animals, springs, and ecosystems of a forest stream. Under his supervising, students who belong to his laboratory and students in PractiSE participated in the creation and implementation of a program for *Yama no Gakko.* The program provides children of an elementary school with knowledge and experience about forests and groundwater through their advantage of the unique characteristics.

Ariake Elementary School was acknowledged by Sapporo City in 1977 as the first small-scale specially acknowledged school to avoid combined classes or schools closing as a part of the school selection system. Sapporo City explains the purpose, "If parents wish their children to cultivate health, physical fitness, and rich humanity in small sized elementary and junior high schools in suburbs with a rich natural environment, children's admission is allowed under certain conditions." (Sapporo City, 2016).

Mt.Shirahata, the place of *Yama no Gakko*, is a mountain (altitude 321.5m) located in Ariake, Kiyota-Ku, Sapporo, adjacent to the city area. Most of the surrounding forests, including Mt. Shirahata, are Sapporo-owned forests, and Sapporo City has designated 1,061 hectares of forests as urban environmental forests for recreational activities such as hiking and nature observation and wood production.

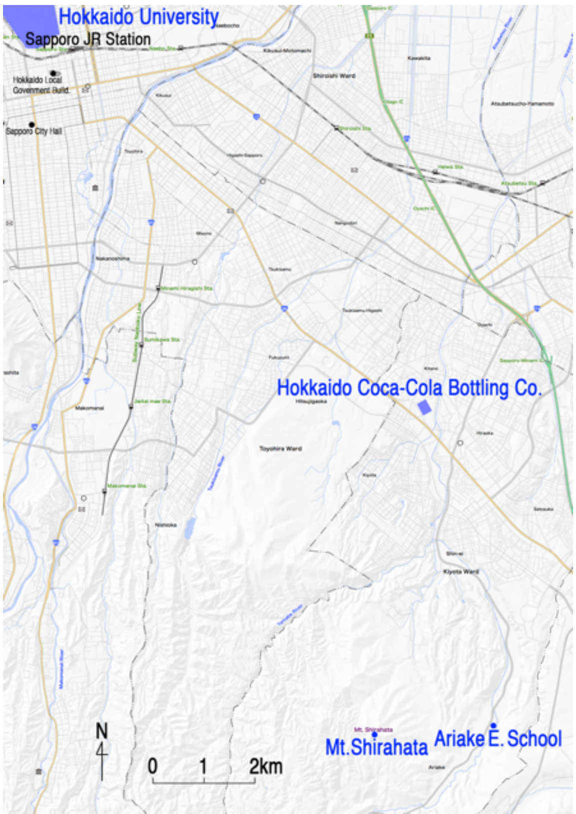


Fig.1 Map of Mt.Shirahata, Ariake Elementary School and Hokkaido Coca-Cola (This map is based on the Digital Map published by Geospatial Information Authority of Japan)

3.2.2. Research and Analysis Methods

The author was the coordinator of the tripartite collaboration and has participated in educational programs implemented from 2013 to 2018. Therefore, the author attended all meetings to implement the educational programs and documented how the researchers developed them. It should be noted that the purpose of this study is a discussion of the program and the results of its implementation by university faculty members and is not the same as the author's action research. A complimentary survey was conducted by interviewing the stakeholders (one university researcher from the Hokkaido University Graduate School of Environmental Science, three staff from Hokkaido Coca-Cola, and two headteachers from Ariake Elementary School). A total of two hours of interviews were conducted with the researcher about intentions of activities, achievements, and his concerns and challenges. We asked the Hokkaido Coca-Cola staff for their thoughts on individual programs and activities as a whole at the post-program review meetings attended by stakeholders and the review meetings held at the end of each year. We also asked the teachers of Ariake Elementary School for their thoughts on the individual programs at the post-program review meetings attended by stakeholders.

As described in section 3, the records showed that the content of our educational programs has been changed and conducted each year for six years without changing its essence. We conducted a supplementary survey considering the specific questions as why the program's essence did not change, why the university researcher created the programs with new iedeas each time, and why they were able to respond to the request for any changes from the elementary schools. Based on those questions, we reviewed the activity records and cross-checked them with the results of the interviews for discussions. As a result, we discussed not only what was "done" as in the question, but also the remaining challenges we found.

3.3. History of *Yama no Gakko* and comments by elementary school teachers participating in it

3.3.1. Environmental education programs in *Yama no Gakko*

Yama no Gakko is an environmental education activity that aims to preserve forests by utilizing the graduate school's expertise in which the Graduate School of Environmental

Science participated in the collaboration between local elementary schools and Hokkaido Coca-Cola. Children learned natural scientific knowledge about nearby nature from natural scientists, who are rarely involved in everyday school education. From 2012, when Hokkaido Coca-Cola celebrated its 50th anniversary, to the present, it has been implemented with the cooperation of Sapporo City, etc. on Mt. Shirahata and the surrounding Atsubetsu River. This study only covers activities for children of elementary schools, although *Yama no Gakko* also has activities for high school students.

In FY2013, the students of the Graduate School of Environmental Science discussed the basic concepts of *Yama no Gakko* and held three events for children of elementary schools. In August, in the "Mt. Shirahata Fureai no Mori," we hosted the event observing insects and investigating bat habitat using a handy-type ultrasonic detector in order to feel the difference of forests between the day and night with our five senses. The 4^{th} to 6^{th} graders in elementary schools in Sapporo and their parents, a total of 25 people participated. In September, in order to understand the significance of planting *Mizunara* "water oak in Japanese" in "Mt.Shirahata Fureai no Mori," we hosted the event measuring the height of the breasts and the distance between trees and reproducing the three-dimensional forest structure using software that simulates the growth of the forests. Thirty of the 4^{th} to 6^{th} graders in elementary schools in Sapporo participated.

In January 2014, we hosted the event playing a role-playing game to understand the entire water cycle: children go around the water cycle, such as evaporation, precipitation, surface flow, soil penetration, and groundwater, with assuming that they had become water molecules, at the Graduate School of Environmental Science. They also detected mineral components in some sample water using reagents. The 4^{th} to 6^{th} graders in elementary schools in Sapporo and their parents, 17 people participated. A total of nine graduate students took the initiative to make and implement programs and review them under the guidance of their teacher.

In 2014 FY, the Graduate School of Environmental Sciences and Hokkaido Coca-Cola have signed a cooperation agreement to cooperate in such as education/research exchange, human exchange, and information exchange in order to contribute to environmental conservation and the development of local communities in Hokkaido. From this year, *Yama no Gakko* had been officially recognized by the Graduate School of Environmental Sciences based on this cooperation agreement. In September, to know the state of the river in the spring area, we hosted the event observing the water springing and aquatic insects captured for each group using microscopes brought from the Graduate School of Environmental Science and explaining their ecology at the spring area in the observation facility in the “Mt. Shirahata Fureai no Mori”. Four graduate students took the initiative in making and implementing programs and reviewing them under the guidance of their teacher. They acquired the school credits. Thirty-eight children in the 4th to 6th grades in elementary schools in Sapporo participated.

From 2015 to the present, based on requests from Sapporo City Ariake Elementary School, the nearest elementary school of Mt. Shirahata, *Yama no Gakko* has been held for 5th and 6th graders in integrated studies. The children of Ariake Elementary School planted *Mizunara* in Mt. Shirahata every spring in cooperation with Hokkaido Coca-Cola and Sapporo forestry union. Ariake Elementary School wanted a program to explain the significance of tree planting to *Yama no Gakko.*

In June 2015, for the first time at Ariake Elementary School, we conducted a program using Lego-Blocks-educational material, a penetration experiment program, and a forest observation program using a drone. To know that forests are groundwater recharge sources, children learned some part of the water cycle in which rain penetrates underground into the forest and becomes groundwater by educational material using Lego blocks and two types of sponges with different water permeability in the classroom. This educational material is reported in Chapter 2. After the indoor experiment, we moved to Coca-Cola Forest in Mt. Shirahata and conducted a sprinkling experiment to examine the difference in permeability experiment to see the difference of permeability between the soft ground covered with litter in the forest and hard bare land. We observed and explained the difference between the natural forest and the planted forest in the video taken from above using a drone. Twenty-six children in the 5th and 6th graders of Ariake Elementary School participated. Ten graduate students took the initiative in making and implementing programs and got the school credits.

In September 2016, we hosted the event experimenting on filtration using Lego blocks educational material in the classroom to learn how rain turns into clean groundwater. The children sprinkled water mixed with colored sand on the educational material and observed how the clear water flowed from the groundwater layer. After that, in the schoolyard, we prepared a group of filtration devices combining mud, sand, and pebbles with different particle sizes prepared in advance and compared the time required for filtration by pouring mud water and the transparency of the filtered water. Twenty-four children in the 5th and 6th grades in Ariake Elementary School participated. Six graduate students took the initiative in making and implementing programs and got the school credits.

Since FY2017, there is no graduate credit recognition system. The university researcher and an external specialist began to make the programs and run them on the day. In June 2017, an experiment using Lego-blocks-educational material was conducted in a classroom to find out that forest soil is easy to infiltrate groundwater. After that, they buried a pipe of 10cm in diameter and 20cm in length, about 5cm in both soft grounds covered with litter layer in the forest of the schoolyard and bare ground, and children sprinkled water in it. The difference in permeabilities was observed by measuring the time of infiltration. The children also dug holes about 50 cm depth in the schoolyard with a scoop and observed the underground soil and plant roots, and the teaching staff explained that the difference in permeabilities is due to gaps in the soil. In that year, a researcher who participated from the Hokkaido Branch of the Forestry Research and Management Organization explained the forest strata to the children as a forest soil expert. Twenty-one children in the 5th and 6th grades in Ariake Elementary School participated. As an example of these programs, we show the time table of the program below (Table 1). The program ran in 90 minutes from the 3rd to 4th periods of Ariake elementary school.

Table 1: Timetable for the educational program conducted in 2017: an experiment using Lego®-blocks-educational material, a penetrability experiment, and a geological observation.

Time schedule	Contents
11:00-11:10	Introduction of staff and today's menu, and ice break
11:10-11:35	Experiment with the Lego®-blocks-educational material. Demonstration of infiltration from precipitation on the forest to groundwater. After finishing the demonstration, disassembling the material and finding its underground structure.
11:35-11:40	Moving the place from classroom to schoolyard, and dividing children into five groups
11:40-12:00	Soil infiltration experiment. In advance, setting five groups of two metal pipes: a pipe in high permeability soil and another pipe in low permeability soil. For each group, guessing which pipe infiltrate quickly, and pouring water on both pipes. Recording the time required for infiltration measured by a stopwatch.
12:00-12:15	For each group, sketching the observed cross section in a place with high permeability.
12:15-12:25	Making a summary of children's experiments and observations by themselves and group presentations.
12:25-12:30	Comments by the university teacher as summarizing this program

In June 2018, we conducted the similar contents in the previous year, the infiltration experiment and observation of the stratum, but the location was in a real forest in the Coca-Cola forest of Mt. Shirahata, although it was shortened to half the time due to hosting *Yama no Gakko* together with another tree-planting event organized by Coca-Cola. We dug a hole with a depth of about 1.4m and about 2m square with a digger in advance. Children went into the hole and observed the stratum, and teachers explained the state of soils, roots of the trees, and the geographical history that can be read from the stratum. We buried pipes made of vinyl chloride on both the soft ground covered with litter layer in the forest and the forest road that had been crushed. Children sprinkled water into them and observed the difference in permeability. As in the previous year, the same researcher from the Hokkaido Branch of the Forestry Research and Management Organization explained the forest strata to the children. Twenty-eight children in the fifth and sixth grade in Ariake Elementary School participated.

For the graduate school to concentrate on program development, Hokkaido Coca-Cola and the Project Design Center held meetings with the elementary school before and after the event, created their minutes, and hosted operation assistance such as taking event photos and movies on the day of the event. Activity costs are borne by Hokkaido Coca-Cola.

Table2. Programs conducted in *Yama no Gakko*

Year/Month	Purpose	Overview	Location
2013.8	To feel the difference between day and night forest with our five senses	Observations of insects day and night, bats' habitat using a simple ultrasonic detector. Twenty-five children of 4-6 graders in elementary schools and their parents participated.	*Fureai no Mori* Forest
2013.9	To understand the significance of tree planting and planting Japanese water oak	Measuring the breast height of trees and the distance between trees and reproducing the three-dimensional forest structure using software simulating the growth of the forests. Thirty children of 4-6 graders in elementary school in Sapporo participated.	*Fureai no Mori* Forest
2014.1	To understand the entire water cycle	Role-playing game walking along the water cycle, and the experiment detecting mineral components in some sample water using reagents. Seventeen children of 4-6 graders in elementary schools in Sapporo and their parents participated.	Hokkaido University
2014.9	To understand the state of the river in the spring area	Observations of the water springing and aquatic insects using micro-scopes. Thirty-eight children of 4-6 graders in elementary school in Sapporo participated.	*Fureai no Mori* Forest
2015.6	To understand forests are one of the sources of groundwater recharge	Experiment using the educational material made of Lego® blocks, a sprinkling experiment onto forest ground and hard bare land, and observations of the forest using a drone. Twenty-six children in fifth and sixth graders of *Ariake* Elementary School participated.	*Ariake* elementary school, Coca-cola forest
2016.6	To understand how rain turns into clean groundwater	Experiment using the educational material made of Lego® blocks, and experiment on filtration using sand and pebbles. Twenty-four children in fifth and sixth grade in *Ariake* Elementary School participated.	*Ariake* elementary school
2017.7	To understand forest soil is easy to infiltrate groundwater	Experiment using the educational material made of Lego® blocks, a sprinkling experiment onto forest ground and hard bare land and observations of the underground soil and plant roots. Twenty-one children in fifth and sixth grades in *Ariake* Elementary School participated.	*Ariake* elementary school
2018.6	To understand forest soil is easy to infiltrate groundwater	Sprinkling experiment onto forest ground and hard bare land and observing the underground soil and plant roots. Twenty-one children in fifth and sixth grades in *Ariake* Elementary School participated.	Coca-cola forest

3.3.2. Comments from participating elementary school teachers

Elementary school teachers generally positively evaluated the contents of various programs related to the natural surroundings of Mt. Shirahatayama and Atsubetsu River. For example, "The graduate school has created significant learning opportunities within every time limited", "Many children have understood what they have learned", "As for Lego® blocks educational materials, even adults were surprised to see that water came out from the groundwater later in time or became transparent in the experiment using Lego locks educational material".

On the other hand, the following problems were found. Each time, we asked the teachers in charge of the program for the contents of the program in advance, but the class teachers in the 5th and 6th grade did not enough understand the program because they did not participate in the prior meetings. Also, students did not have any prior learning. The elementary school teachers described as "Having a prior learning before outdoor experiments and observations will deepen children's understandings," "Distributing pre-learning materials is helpful."

3.4. Discussions

The program of *Yama no Gakko* activities had been changed each year depending on the season, the target participants, the availability of graduate students' participation, and the area of expertise of the students. The discussions focus on the role played by university researchers in their work with Ariake Elementary School, which took place between 2015 and 2018, and examine the characteristics of the programs and educational materials developed, the challenges overcome by the researchers, and the remaining challenges.

Based on the records of activities and interviews with the people involved, the three following characteristics were found in the programs implemented in *Yama no Gakko* over the past four years.

(1) The program structure, which was designed to deepen children's understandings of the program in the limited time of two periods, is a form of academic research.

(2) Educational materials have been developed using familiar materials to attract children's attention and make them easier for elementary school teachers to handle, and academic explanations were given with them.

(3) University researchers participated in a way that enables them to use their resources, such as researcher networks and the creative minds of researchers.

3.4.1. Program structure having similar structures to the format used in academic research

The basic structure in scientific papers is usually called the IMRaD structure: Introduction, Methods, Results, and Discussion (Masuda et al., 2017). The "Introduction" points out the research question based on summarizing what has been cleared in the academic discipline or not. The “Method” describes how researches are conducted as the third party can reproduce them. In “Results”, the data obtained by the researches are organized and shown. It describes the facts leading to what the results indicate scientifically. In “Discussion” describes the author’s ideas and interpretations, using the obtained results. At last, researchers publish their papers structured above.

In *Yama no Gakko* programs, children learn through a process similar to the IMRaD structure: (a) raising a question, (b) experiments, (c) organize data, (d) interpretations, and (e) presentations. For example, the (a)-(d) structure can be seen in the programs conducted in 2015, 2017, and 2018 to understand the permeability. First, (a) the question of why forests are the source of groundwater was raised (Lego® blocks materials were not used in the 2018 program due to limited time). Next, (b) an experiment was conducted as the water was sprayed on the ground at two locations, the forest part and the bare part, and the infiltrate time was measured.. Finally, children observed the actual formation and (c) using the data obtained in the experiments, (d) confirmed that the difference in permeability was caused by the difference in soil gap due to soil particle size, plant roots, etc., and (e) presented in each group. The filtration experiment of the muddy water conducted in 2016 had a similar structure in 2018 as follows. (a) Educational material using Lego® blocks showed that filtration was essential for rainwater to become clean water that can be used. (b) Next, each group made the filtration device using natural materials, such as sand and pebbles with different particle sizes, poured muddy water onto it, and measured the time required for filtration. (c) The time required for filtration and water transparency was compiled for each group, and (e) presented their results. (d) The children found that filtration making clean water required a soil layer with a small particle size, which took a long time by comparing the results of each group.

The professor says, “I want to make time to think why in the program not only to convey a little advanced knowledge unique to the graduate school.” That is, the above structure is intentionally made every time.

On the other hand, as mentioned in section 1.2, usually elementary schools use a similar process in observation and experimental learning. The “Guide to observation and experimentation in science lecture of elementary schools” notes that observations and experiments should not be conducted without children’s motivation and understanding to know the meaning of them. Therefore, prior learning is carefully carried out.” In *Yama no*

Gakko program, the researcher also raised the issue and made children think about the purpose of the experiment. As the researcher remarked in a review meeting, "I would have liked to have a little more time to make them think," there was not enough time for children to think in the IMRaD format. According to the Guide, it was required to give the children time to think about the background and purpose of the experiment as well as the children's preliminary answers for the experiment results. An elementary school commented that the experiment started out of the blue and some children were confused. Children do not learn enough beforehand to have their ideas, as elementary school teachers commented, "Children would understand better if they had prior learning before the experiments and observations outdoors." The teachers' comment, "Providing materials would be helpful for children to do prior learning," is an understandable opinion.

The IMRaD format is a learning style accepted by children, as it is similar to the process of learning in elementary schools. Providing prior learning materials in advance will work effectively for children's motivation and understanding of the meaning of the activity and lead them to learn more in depth. For prior learning, it is advisable to provide information on the purpose and specific contents of the program, materials to be used, timetable, etc.

3.4.2. Development of educational materials that represent the essence of nature with familiar materials and expertise explanation

Most of the educational materials and equipment used in the program are made from inexpensive materials easily available. University researchers are familiar with the measurement principles of the equipment used in research and are familiar with the mechanisms of phenomena occurring in nature.

Therefore, it is possible to develop experimental educational materials with familiar materials. Such educational materials can be disassembled to explain the principles and elements of nature. It can also be improved according to the situation.

As discussed in Chapter 2, the educational material using Lego® blocks and sponges, infiltration experimental equipment, and filtration experimental equipment are used in the programs of *Yama no Gakko*. For example, the equipment used in the experiments on infiltration capacity is metal tubes with an inner diameter of about 10 cm, 500 ml PET bottles, and stopwatches, and used in the experiments on filtration experiments are three types of fluids with different mesh size, 2000ml and 500 ml PET bottles, and stopwatches.

Educational materials made with such familiar materials are preferable for elementary school teachers.

Takeuchi (2013) reported that she developed a science-educational-material that anyone could make at low cost using the available materials in the long-term trainee system. As said in this report, university researchers developed educational materials using familiar materials in *Yama no Gakko*.

In the programs using these materials, university researchers explained the principles of larger natural phenomena and the need for forest and groundwater conservation. In the infiltration experiment program, he and his collaborator showed that water penetrates more easily in forests than on bare land, both through experiments using Lego® blocks materials to visualize the underground structure of forests and through sprinkling experiments in actual forests. In this experiment, we explained that on bare land, rainfall flows over the surface and into rivers, swelling the river water in a short period of time, while in forests, rainfall is stored once in the soil and takes time to infiltrate the groundwater layer and runoff into rivers. The children learned their tree-planting activities nurture groundwater and prevent sudden river swells.

In the filtration program, an experiment in which water mixed with colored sand was sprinkled on Lego® blocks materials showed that water is filtered through the process of groundwater recharge. Another experiment to build a filtration system showed that it takes time to filter the water cleanly. These experiments explained that the groundwater at Mt. Shirahata used by the beverage manufacturers was filtered over 70 years. Children learned groundwater recharge takes a long time and reforestation requires long-term commitment.

Through the program observing the strata, children observed that the forest soil is clustered structure near the surface, with a large number of plant roots in the underground, showing that there are gaps around the area that allow water to penetrate easily. They observed that the lower part of the soil stored water because the lower layers of the soil had fewer tree roots and water was not absorbed by the trees. They went into the 1.4-meter-depth hole and touched and watched the stratum, soils, and roots, and learned that the forest is a green dam.

In these programs, university researchers explained events occurring in nature on time scales ranging from hours to decades, as well as on large spatial scales by the results of experiments using simple educational materials. Elementary school teachers rated the quality of the educational materials highly, as they remarked, "Even adults were surprised when water came out from the groundwater layer in a time-delayed or filtered through the Lego® blocks materials."

However, the educational materials and explanations produced by university researchers are in a similar situation to the case of curatorial trunk kits, as discussed in 1.3. Lego® blocks are familiar material to children, but as the elementary school teachers pointed out, "they are different from natural materials." Therefore, children are not always easy to understand natural phenomena by this material. The materials used in the educational programs are easy for teachers to handle, but explaining the order of natural phenomena in a program using them requires specialized knowledge. We conducted an experiment using Lego® blocks educational material and asked ten elementary school teachers around Sapporo for their opinions about it. As a result, eight teachers requested expert lectures for using it. Similar to the case of trunk kit, the activity *of Yama no Gakko* also requires explanations by university researchers "*Demae* lecture" (university teachers going to elementary or high schools to have a lecture) or elementary school teachers learning about expertise and teaching techniques from university researchers beforehand.

3.4.3. Involvement that makes use of the resources the university researcher has

Ariake Elementary School asked us to make the program students understand the significance of the annual tree-planting activities, and to avoid the same program two years in a row since the program was conducted for the 5th and 6th graders. In addition, the graduate school had difficulty applying students' research to the program because the area of expertise of participating students changed every year, and credit as a course in graduate school was no longer given and few students participated since 2017.

Under these changing circumstances every year, the university researcher conducted eight different programs in four activities between 2015 and 2018, including two experiments with Lego® blocks materials (forest groundwater recharge and filtration), two soil permeability experiments (schoolyard and forest), forest observation with drones, filtration experiments with natural materials such as pebbles, and two forest soil observations (schoolyard and forest).

The following two university researchers' resources contributed to enabling him to respond to these changing situations. One was the unique researcher network the researcher had. In the activities in 2017 and 2018, he found the collaborators from his research network and developed new programs with their help on forest soils outside his expertise. As a result, the elementary school was able to access the researcher's network through university researchers and receive new program offerings to learn the significance of reforestation activities. The other was the creative mind of the researcher. As he said in the interviews, "If we're going to do the same program every year, the researcher doesn't have to do it," it was a prerequisite for researcher's participation that researchers have the discretion to exercise their creativity in program development. Implementing a different program each time is generally difficult because it takes time and effort. However, university researchers are always looking for new elements to develop programs in environmental education programs as well as research into unknown areas. In other words, even without requests from elementary schools or changes in the situation of graduate students, university researchers would have always developed new programs that incorporate new elements. In environmental education activities university researchers participate in, it is necessary to manage the entire activity with a good understanding of the mind of such researchers.

Clarification of the roles played by university researchers is necessary for their activities. In the interviews, the university researcher said, "There is no function in the graduate school to approach the elementary school to implement an environmental education program, to understand their needs, to set up meetings, and to adjust the implementation schedule." The Hokkaido Coca-Cola and the Project Design Center (to which the author belongs) held and recorded preliminary meetings with the elementary school and post-event review meetings, assisted in the management of the event, and took photos and videos of the event so as to help the graduate school to focus on program development and implementation. In this way, there needs to be a division of roles so that university researchers could focus on program making.

3.5. Conclusions and Future Challenges

Sub-committee relevant to environmental thought and education, Committee of Environment, Science Council of Japan (2008) recommended that universities are expected to play a role in collaboration with elementary and junior- and senior-high schools, as a core of the environmental educations in the regions.

However, this recommendation does not show the specific role of university researchers and the important factors for collaboration. . This study investigated as a case study the nature experience and environmental education programs for the 5th and 6th graders at Ariake Elementary School at Sapporo, which is implemented as *Yama no Gakko* by the Graduate School of Environmental Sciences and Hokkaido Coca-Cola Bottling under a cooperative agreement. We found three characteristics and challenges of the programs when university researchers are proactively involved in environmental education in elementary schools as academic experts.

First, the programs had a process similar to the structure used in academic research (IMRaD structure). Although the children learned in the programs of scientific logical composition, the two periods were too short for the children to organize their ideas and did not provide time for prior learning, which is important for observations and experiments in elementary schools. Prior to the implementation of the programs, university researchers should have explained their content to the elementary school teachers in advance, and the children could learn more deeply by prior learning.

The second, educational materials were developed to represent natural phenomena using familiar materials for children, and specialized explanations were provided using them. However, the explanations with them require an understanding based on expert knowledge of the natural sciences, and it was difficult for elementary teachers to master them on their own. In order for the educational materials to be used in elementary schools, as in the first case, it is necessary for elementary school teachers to have opportunities to learn expertise and teaching techniques from university researchers before the implementation of the program, or to receive expert dispatches, such as *Demae lectures*, as it was done in *Yama no Gakko*.

The third is two resources, the research network and the creative mind of the researchers, which were utilized in the development of the program. He found the collaborators from his research network and developed new programs with their help. The other is to allow university researchers to have the flexibility to use their creativity in program development. It will be a prerequisite for their participation. It is also necessary to divide the roles so that university researchers could focus on program development and other actors do supportive tasks, such as proposing and meeting before the programs.

University researchers were able to implement programs by using their abilities and knowledge because the logical structure used in academic research was close to the way of elementary school observations and experiments, and the development of educational materials with familiar materials to represent natural phenomena was supported by expertise in the natural sciences. However, it is important to note that creating pre-learning opportunities for children directly is a difficult task, and communicating with elementary school teachers is necessary in advance, such as creating opportunities to teach them expertise and instructional techniques and communicating the content of the programs in advance. If universities collaborate with elementary schools in environmental education, this should be done with a full understanding of the characteristics of such university researchers.

Chapter4. General Conclusions

4.1 Summary of Chapter2 and 3

This doctoral dissertation discussed and clarified the following in Chapters 2 and 3 using a case study of a four-year activity of *Yama no Gakko* as an educational program conducted by a graduate school, a corporation, a non-profit organization, and a local government in collaboration with an elementary school.

Chapter 2 focused on an educational material of groundwater developed by university researchers. This educational material helps children to understand following two things, "Forests are the main groundwater recharge area" and "Groundwater has a longer residence time than surface water." The educational materials are made of familiar materials to children, such as Lego® blocks and sponges, and its structure consists of three layers, surface, shallow and deep layers, and water penetrates underground from the surface in the mostly forested parts on the ground mainly. This material is designed concerning the JMA's three-storage tank model, with time differences of water outflows from the three layers. As the educational material is placed at an incline downstream and sprinkled on the forest area, the outflows from its downstream part a have higher and earlier peak in the upper levels and a lower and gentler peak in the lower levels. This material quantitatively was confirmed to represent two scientific facts: forests are the main groundwater recharge area, and groundwater has a longer residence time than surface water. This result showed that the material was visualized for a three-storage tank model with groundwater characteristics and supported by scientific knowledge.

Chapter 3 revealed the characteristics and challenges of environmental education programs in the elementary school developed by a university researcher as academic professionals by recording activities and interviewing stakeholders. These have the following three characteristics.

As the first characteristic, the structure in these programs was according to a common organizational structure called the IMRaD: Introduction, Methods, Results, and Discussion. Based on this structure, the programs provided time for children to predict the results as their working hypotheses before their experiments and to discuss their results after their experiments. The program structure, allowing children to have a perspective on the results of the experiments and to draw their own conclusions, was consistent with the subject objectives of elementary school science, "The goal is to develop the qualities and abilities necessary for students to scientifically solve problems related to natural things and phenomena through familiarity with nature, application of scientific views and ideas, and observation and experimentation with a clear perspective.” (MEXT, 2017). However, he did not have enough time for children to be interested in the program and develop methods for observation and experimentation beforehand, as it is done in the prior learning that is important in elementary school observational and experimental education (MEXT, 2011). Because the programs covered quite a lot of content in 90 minutes, elementary teachers must conduct prior learning that is not currently done. Therefore, communication about the program’s content and the information necessary for prior learning should be conveyed to elementary school teachers by university researchers in advance.

As the second characteristic, scientific explanations were provided using handcrafted educational materials made with familiar materials. Of course, the educational materials represent scientific knowledge, as mentioned in Chapter 2. Universal teachers thought that even elementary school teacher would be able to easily create and use by themselves because they were made of familiar materials. However, since explaining using these educational materials requires specialized knowledge, many elementary school teachers commented that if they actually use the materials, they would ask for experts, such as university researchers, to be dispatched. For using these educational materials in elementary schools, university researchers are required to go to the classroom, or elementary school teachers are required to learn expertise and teaching techniques from university researchers in advance. This is similar to the challenges faced by the Trunk Kit, a learning resource developed by museum curators or other experts. The interviews with the elementary school teachers suggested that the explanations using the educational materials were not always easy for the children to understand because the materials were not made of natural materials. The order of the program should be kept in mind: first the actual experience of tree planting activities, and then the explanation of phenomena that cannot be actually seen with the eyes using this material.

As the thirdly characteristic, the two resources of the university researcher, his research network and creative mind, are utilized. There were new requests for the program from elementary schools, the students in the graduate school participating changed every year, and no more students participated. Under these changes in circumstances, a university researcher found the collaborators from his own research network and developed new programs with their help. Even without these changes in circumstances, the interview survey confirmed that the researcher used creativity to change the program and conduct new program every time. In environmental education activities in which university researchers participate, it is essential to understand enough about the creativity of the researchers and manage the entire activity.

4.2 Suggestions based on this dissertation

In this case study, "*Yama no Gakko,*" Ariake Elementary School currently wishes to continue these activities. In the external evaluation committee of *Yama no Gakko*, members of Sapporo City, environmental NPO, and Hokkaido Coca-Cola expressed their hopes for the continuation of these activities every year. Researchers from outside research institutions, who have participated for two consecutive years since 2017, have also expressed a willingness to take part in. In this way all stakeholders want it to continue. However, if the collaboration between graduate school and elementary school is to continue in the future, there is a need to reduce the burden on specific sectors and individuals by creating a way of working together and a system to support it in program development and prior learning. In addition, for better environmental education with the participation of university researchers, this study suggests the following, not only for *Yama no Gakko*. Many university researchers provide environmental education for elementary school students, which succeeded to some extent because of its program structure according to the IMRaD structure, the ability to develop materials based on scientific knowledge, human networks, and creativity. However, it became clear that the program's challenges to be understood if university researchers' programs are going to be better. For example, the IMRaD structure is similar but different from the prior learning emphasized on observations and experiments in elementary school science. The creativity of university researchers comes into play in developing educational materials made of familiar materials. While anyone can make educational materials because they are made of familiar materials, anyone cannot interpret and explain natural phenomena with them, which requires specialized knowledge and skills. To overcome that weakness, university researchers and elementary school teachers must inform each other, such as what they value in each other.

University researchers and Elementary school teachers should share their needs and information required to better implement the programs; for example, the former trying to develop creative new programs, the latter needing to implement prior learning to motivate children and desiring to have a program well connected to the content taught in the class, as well as each other's motivations, merits, and demerits for implementation. If such an exchange of information is implemented, then we can provide programs that allow children to learn more deeply.

One feature of the "*Yama no Gakko*" not discussed in this study is the participation of graduate students in developing and implementing the program. In the activities of the "*Yama no Gakko*" until 2016, graduate students had the leading role in developing the programs and implementation under the supervision of the university researcher, who was the main person in developing the program. When graduate students have the leading role, the disadvantage is that the contents and level of the programs provided are highly dependent on their expertise and communication skills. However, the supervisor commented that it was a valuable learning experience for the students. The elementary school teachers commented that the children enjoyed learning as graduate students who were more familiar to them and international graduate students with whom they rarely interacted, which are advantages of teaching by graduate students.

The personal personality of the university researcher who is the target of this study, such as being positive in educational activities outside of the university, may be one of the factors for obtaining high assessment of the environmental education program, "*Yama no Gakko*." The discussions in Chapters 2 and 3 were tried not to rely on a single case with reference to the experiences of the author's supervisor, who has many opportunities to teach children. However, these cannot be confirmed by these case studies alone. Therefore, further research is needed to more objectively describe the key points that university researchers make when providing environmental education in elementary school.

This doctoral dissertation provides an example of how groundwater can be studied from the perspective of the water cycle. The educational materials and educational programs clarified in this study can be used to study the water cycle in elementary school classes as an approach to the SDGs (especially Goal 6 and Goal 15).

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