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AN INSTRUCTIONAL DESIGN USING THE VIRTUAL ECOLOGICAL POND FOR SCIENCE EDUCATION IN ELEMENTARY SCHOOLS*

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ABSTRACT

Ecological ponds can be a good teaching tool for science teachers, but they must be built and maintained properly to provide students with a safe and suitable learning environment. However, many schools do not have the ability to build and maintain an ecological pond. This study used virtual reality technology to develop a web-based virtual ecological pond, supported by situated learning theory and the instructional design of "Aquatic Life" learning unit. Elementary students can explore in the virtual ecological pond to observe aquatic plants and animals for obtaining important concepts of aquatic ecology. A teaching experiment was conducted to investigate the learning effectiveness of this instructional design, and the results showed that using the virtual ecological pond could improve students' critical-thinking ability. Most students found the virtual ecological pond interesting and easy to use, so it is helpful to learning aquatic life and ecological conservation.

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1. INTRODUCTION

The Ministry of Education, Taiwan [1] proposed that "Environmental education is about the interaction between people and their environments, and the goal is to help students understand and solve environmental problems and create the concept of a sustainable society." In order to instill these concepts into the younger generation, a sustainable campus is a worthy and directly useful topic [2], based on which students can realize the importance of maintaining good relationships between humans and their environments, understand the environmental issues occurring in or caused by schools, and learn how to improve campus environments. Through the guidance of teachers, students can develop their awareness about campus environments and the knowledge of natural environments. Gradually, they will establish environmental values, develop their independent thinking and problem-solving skills, and take part in creating and improving a sustainable campus.

The learning objective of environmental education emphasizes reflecting real life to enhance students' skills and experiences in their environments, and it thus increases the importance of ecological gardens in school education. An ecological garden not only provides substantial teaching materials but also is a suitable place for students to observe and conduct experiments. Luo [3] suggested that incorporating actions and daily experiences into learning can improve students' ability in solving real life problems. Therefore, teachers and students together can cooperate in the development, management, and maintenance of ecological gardens to create a sense of identification and belonging.

Wang [4] found in her study about the ecological education in Taiwan's elementary schools that a broad range of ecological teaching resources, for example, ecological ponds and botanical gardens, could be considered as ecological gardens. Fang [5] defined several forms of ecological gardens in campus, for example, aquatic plant areas, honey plant areas, natural pathways, nursery areas, and organic compost areas. Yang and Lee [6] also proposed the following forms of ecological garden: aquatic ecological area, bird watching area, butterfly area, forest area, and grassland area. Therefore, ecological gardens can be built according to the educational requirements and environmental features of schools. Basically, aquatic plant areas and aquatic ecological areas are indispensable parts of aquatic ecological gardens, and they are very useful in teaching natural science in elementary schools [7].

The idea of using ecological gardens in science teaching provides students with a simple, observable and practical learning environment on a small scale. Combined with the curriculum design and development, ecological gardens can be used for teaching students about environmental protection and conservation in campus by allowing these important concepts to be realized.

In addition, learning topics about aquatic life are common in elementary science curriculum, for example, "Major features of aquatic plants and animals" and "Observing animals through breeding" in Grades 3-4, "An introduction to population" and "Ecological conservation" in Grades 5-6. An ecological pond provides teachers with abundant teaching materials and a safe and economical outdoor teaching environment. It can also improve teachers' teaching skills and gives students a concrete and practical learning environment [8].

1.1 Ecological Ponds

In recent years, experts and scholars have engaged in researches about ecological ponds. A research report released by the Ministry of Interior, Taiwan [9] described that "An ecological pond is an ecological system in the city or countryside which possesses an ecological chain and suitable climate; the pond should have sufficient area, suitable depth and shape, non-permeable bottom layer, sufficient water source, and porous materials to provide indigenous plants with a complex living area, and all above form a complete ecological system where plants and animals can coexist and live with very little human assistance."

The Ministry of Education in Taiwan conducted a survey on the ecological teaching resources of Taiwan's elementary schools and the results showed that 63% of them had ecological ponds, among which 60% were frequently used in teaching [10]. It is apparent that the importance and usage of ecological ponds have increased based on the needs of elementary science education. However, in addition to suitable campus environments, a lot of manpower and resources are also required for the construction of an ecological pond to satisfy the needs of science teaching. Besides, maintenance and safety management is also very important after building an ecological pond, and these all affect whether it would be worthy to build an ecological pond for educational purpose.

According to the "General Guidelines of Grades 1-9 Science and Technology Curriculum" [1], the construction of an ecological pond is helpful to science education, and it also reduces the workload of teachers in preparing teaching materials. Because many schools do not have the manpower and resources to construct, manage, and maintain an ecological pond, it is very helpful if someone could build a web-based virtual ecological pond for applications in science education. Meanwhile, students can also observe and learn by themselves using the virtual ecological pond conveniently.

1.2 Situated Learning Theory

Situated learning emphasizes that knowledge must be presented in a realistic situation. In other words, education has to be revolutionized based on social environments and scientific researches such that students can observe and interact with others in a real living environment when solving problems to encourage their cognitive and learning requirements.

Burner [11] believed that learning activities involving discovery or creation could provide students with the ability to develop, induce, and apply their knowledge to understand its meaning. Brown, Collins, and Duguid [12] also believed that learning should exist within learners and their environments. In science education, students' living environments form the background of learning and real life problems should be the center for developing their knowledge. In this way, students can build up meaningful knowledge and apply it in solving practical problems. This is the concept of learning based on the needs of real life, emphasized by many science education researchers [13-15].

This study was based on the theory of situated learning. In terms of learning situation, a virtual ecological pond can help students combine its contents with the knowledge acquired from the real world, which allows students to become familiar with aquatic plants and animals as well as understand the importance of ecological conservation. From the viewpoint of teaching methodology, the instructional design and strategies enabled students to explore and discover in the virtual ecological pond, and the objective was to help students understand the meaning of aquatic ecology and its conservation.

1.3 Virtual Reality

Virtual reality is a technology to simulate real environments by human sense organs. Combining with stereo visual effects and other sensory interfaces, we can see, hear, and feel in the virtual scenes, and even interact with others in the virtual environments. Virtual reality can simulate the phenomena and display some concepts and experimental procedures difficult to present or observe in the real world. It can also create a learning environment to match the teaching objectives or stimulate human brain's learning activities, and the major purpose is to help students acquire knowledge and understand the meaning of abstract concepts and principles [16].

Three major factors are essential for the creation of virtual reality: interaction, immersion, and imagination [17]. These factors entirely determine how "real" a virtual world could be, and they provide an important standard for evaluating the quality of a virtual reality system. In recent years, modern technologies paved the way for the development of virtual reality, and many scholars began to study its application and influence on education. For example, Taylor and Disinger [18] investigated the feasibility and acceptability of virtual reality in environmental education, and they discovered that virtual reality provided students with many valuable experiences not available in real life. Hence, it was very helpful in environmental education.

Virtual reality can be used to present educational information in visual and tangible manners instead of abstract concepts and static images [19]. In a virtual environment, students can observe from different angles and interact with the environment in different ways to create a deep impression. With the design of further interactive functions, virtual reality can provide students with more natural and intuitive learning experiences [20]. When virtual reality is used to create an interactive learning situation, students will be able to manipulate in the virtual environment to observe the results and correct their notion to enhance problem-solving skills. This process of transforming abstract knowledge to concrete experiences can make up for the deficiency of "putting knowledge into practice" in traditional educational systems [21].

This study combined virtual reality technology with the instructional design of "Aquatic Life" learning unit to create a virtual ecological pond, and its purpose was to solve the problem of many schools without ecological ponds for usage as a teaching resource. In this study, students could visit the website to learn about aquatic plants and animals in the virtual ecological pond. They could control their viewing angles and positions, and dive into the ecological pond to see different types of submerged aquatic plants, aquatic insects and fish. They could also play the games of removing Pomacea canaliculata and sponges to understand the influence of dominant species and foreign species on an ecological system.

1.4 Research Objective

A virtual ecological pond provides students with a learning environment to simulate real situations, where they can observe, operate and experience through online learning activities under the guidance of teachers or parents. In the meanwhile, they can also relate these experiences to the real world in practice. Under the framework of situated learning theory, this study used virtual reality to develop a virtual ecological pond based on the teaching plan and strategy of "Aquatic Life," a learning unit in the natural science curriculum of elementary schools. Students can observe aquatic plants and animals in the virtual ecological pond through networks and it thus solves the problems of being not able to build and manage a real ecological pond in many elementary schools.

To provide abundant knowledge about aquatic life, the virtual ecological pond displays many types of aquatic plants and animals, together with detailed information for immediate reference. Students could use the control keys and mouse to move around, and switch their viewing angles above or under the water. A game-based learning activity was designed to remove the eggs of Pomacea canaliculata and sponges. The system provides instant feedback through an interactive mechanism to show the influences of foreign species and dominant species on the ecological system. Therefore, students could experience the fun of "learning while doing" when developing the concepts of ecological conservation.

2. RESEARCH METHOD

In this study, the design of virtual ecological pond incorporated the teaching materials of "Aquatic Life," a learning unit in the natural science curriculum of elementary schools. This study first analyzed the learning requirements, and then designed the system according to its learning objectives. Because situated learning emphasizes realistic learning activities, a connection to campus environments was emphasized to provide students with a learning experience that is similar to real life situations.

2.1 Analysis of Teaching Materials

The teaching materials of "Aquatic Life" and some related learning contents in several textbooks about ecological ponds were analyzed first to determine the learning objectives for the instructional design using virtual ecological pond, which are listed in the following:

- To know different aquatic environments:
  - Various aquatic environments in our surroundings;
  - The characteristics of aquatic environments;
- To identify aquatic plants:
  - According to how they grow in water, aquatic plants can be categorized as free-floating plants, submerged plants, rooted-floating plants, and emergent plants;
  - The stems and leaves of submerged plants are tender and slender;
  - The free-floating plants have a small body and their leaves are filled with air;
- To identify and recognize the characteristics of aquatic animals:
  - The fish, aquatic insects and amphibians;
  - The insects near the aquatic environments;
  - Aquatic animals move or swim using different parts of their bodies;
- To care about the ecological pond:
  - Protecting the environment of the ecological pond;
  - Understanding the influence of dominant species and foreign species on the ecological pond; and
  - Teaching students not to abandon animals in the ecological pond;

2.2 System Design

This study combined the instructional design of "Aquatic Life" learning unit with virtual reality technology to create a virtual ecological pond for applications in elementary science education. Due to a large number and the variety of aquatic plants and animals for simulation in 3D virtual environments, it was decided to use simpler models for the reduction of file size and computation time. The design of virtual ecological pond and the 3D models of aquatic plants and animals are described below.

Virtual Ecological Pond

The virtual scenes developed in this study included: a campus and two ecological ponds. The campus of Hsinchu Elementary School, Hsinchu was imitated to create a realistic situation for the induction of more concrete learning and cognition. The reason for choosing this school as the model of virtual scene was that the teaching experiment in this study would be conducted here later on. After entering the virtual campus, students could see a long row of classrooms with many palm trees and Juniperus chinensis. There were also golden dewdrops and banyan trees in the green grass. Since there was no ecological pond in the campus of Hsinchu Elementary School, the design of virtual ecological pond was based on the floor plan of Shuang Lian Elementary School (see Figure 1), a successful example of using recycled rainwater drawn into an artificial ecological environment. The ecological pond had pathways around for students to observe aquatic plants and animals at a close distance.

According to the floor plan, the virtual campus was designed using the pictures of Hsinchu Elementary School as texture images. A virtual wall was constructed to limit the walking area within the campus and it could prevent students from wandering away. There were palm trees, banyan trees, Juniperus chinensis, and golden dewdrops scattering around to create the feeling of a realistic campus while it could also increase students' knowledge about common plants (see Figure 2).

There were pathways around the virtual ecological ponds for students to observe the aquatic plants and animals at a close distance. Besides submerged plants and aquatic animals, there were rocks, sunken woods, and pond water to create a lifelike visual effect under the ecological pond (see Figure 3). In order to simulate the growing environment of aquatic plants, the inclination of the pond bottom was reduced and fine sand was used as the material at the bottom with slowly varying depth.

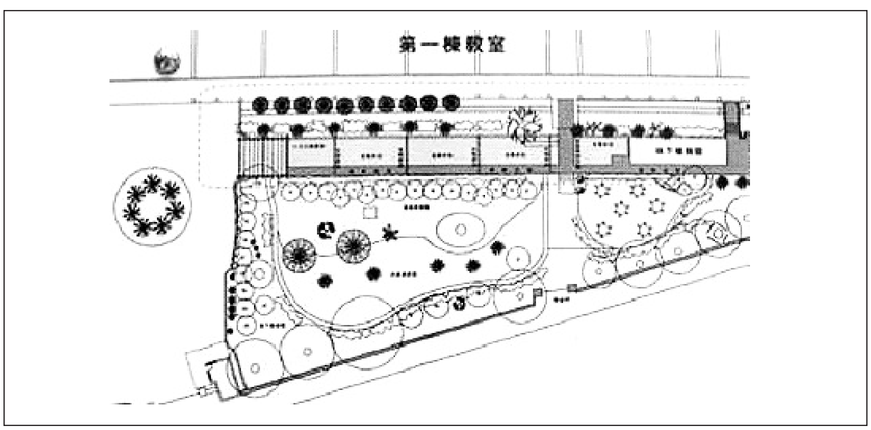

Figure 1. The floor plan of ecological pond at
Shuang Lian Elementary School, Taipei,

Figure 2. The virtual campus of Hsinchu Elementary School, Hsinchu.

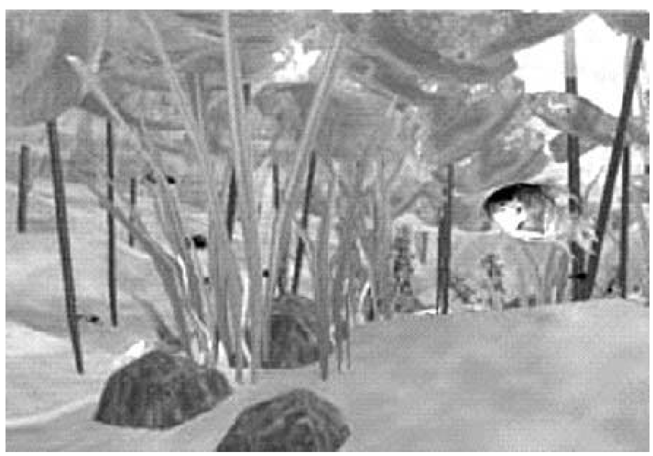

Figure 3. The underwater view of virtual ecological pond.

Two red pyramids were placed at the shore and bottom of the ecological pond as the switches for students to pass through the so-called “virtual channel” (see Figure 4). By clicking on the pyramids, students could change their positions by “diving into” or “floating above” the water. They could also change the viewing angle by pressing the “Page Up” and “Page Down” keys to look at the target more clearly. The design of “virtual channel” provided an efficient way for observing underwater ecology.

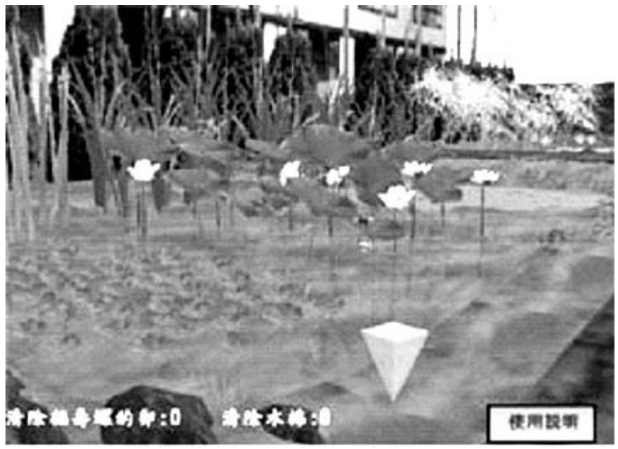

Figure 4. To change position by clicking on the red pyramids.

Aquatic Plants

Aquatic plants generally refer to plants living in water, and they are different from land plants since they rely on water more. Although all aquatic plants grow in water, they can still be divided into several types based on how they deal with different water depths and their movement in water. Depending on whether their roots are in earth, aquatic plants are divided into free-floating plants and plants rooted in earth, and the latter can be further divided into submerged plants, rooted-floating plants and emergent plants.

These four types of aquatic plants were arranged in different sections of the ecological ponds. Usually, emergent plants grow on the pond edges, for example, Schoenoplectus mucronatus, Cyperus alternifolius, Colocasia esculenta, Typha latifolia, and Hydrocotyle vulgris. Rooted-floating plants grow in water with leaves floating on water surface, for example, Nuphar shimadai Hayata (indigenous species), Trapa maximowiczii Korsh, and Marsilea. Submerged plants grow at the pond bottom, completely underwater, for example, eelgrass and Egeria densa. The roots of free-floating plants do not touch the pond bottom but the entire plants float on water surface, for example, Azolla, water cabbage, and duckweed.

The procedure for developing virtual aquatic plants includes: determining species, designing texture images, creating models and reducing the number of images.

- Determining species

  The authors studied the aquatic plants appearing in the textbooks of elementary schools to find out the most common and indigenous species in Taiwan for inclusion in the virtual ecological pond.

- Designing texture images

  Designing texture images is an important task when creating the 3D models for aquatic plants. The texture images were obtained by taking pictures of aquatic plants and scanning images in textbooks.
- Creating 3D models

  There are two different approaches to creating the models of aquatic plants, depending on the shape and complexity of aquatic plants. The traditional approach has better visual effects but it usually incurs more complex models and larger file sizes. The crossed-section texture mapping approach is done by pasting images on two intersecting planes, and it is often used to simulate plant models.
- Reducing image size

  The complexity of models and the resolution of texture images are the major factors affecting the file size and reality of 3D models, so it is important to make effective use of texture images. The designers used Photoshop to create a composite image to accommodate more texture images of aquatic plants and it could effectively reduce the number of images and file sizes.

Aquatic Animals

The procedure for developing virtual aquatic animals includes: determining species, creating 3D models, designing texture images and motions. In creating the 3D models, the designers must consider their sizes and the resolution of texture images to reduce the file size and make the models suitable for observation. A description about each step is given in the following.

- Determining species

  The aquatic animals in the virtual ecological pond mainly consist of aquatic insects, fish, shellfish, and amphibians (see Figure 5). Among them, Pomacea canaliculata, Dytiscidae, fossil dobsons, Laccotrephes Macropodus opercularis, tadpoles, and Gambusia affinis live in water; Gerridae, dragonfly, damselfly, and Guentheris frog live around the ponds and on the water surface as well.
- Creating 3D models

  When creating 3D models, the designers must make sure that all animals have a proportional scale and then use 3ds Max to create the models according to their pictures.
- Pasting texture images

  When designing texture images, the photos of aquatic animals were scanned into suitable images. Then, the UVW function of 3ds Max was used to paste the images to surface of the model. After that, the Unwrap UVW function was used to adjust the images to make the model more realistic.

Figure 5. The aquatic animals in the virtual ecological pond.

- Designing motion

  The designers simulated the motions of aquatic animals by analyzing their behavior based on some video or observation. For example, a damselfly has three sets of motions, including flying above the water, toughing the water surface, and stopping at a plant (see Figure 6).

3. TEACHING EXPERIMENT

In this study, a teaching experiment was conducted to investigate the effectiveness of instructional design in "Aquatic Life" using virtual ecological pond. In addition, the authors would like to know the reactions of students after using the virtual ecological pond. A description about the experimental design and evaluation tools is given below.

3.1 Experimental Design

This study randomly selected two classes of 3rd grade students (31 students in each class) from Hsinchu Elementary School as samples. One class was acting as experimental group and the other was acting as control group. The former adopted the instructional design using virtual ecological pond and the latter adopted traditional teaching method using PowerPoint slides and video as instructional media.

Limited by the sampling method and the number of samples, this study adopted the nonequivalent-groups pretest-posttest design, which adjusted the difference of students' background by means of the analysis of covariance (ANCOVA) to investigate the influences of different teaching methods and student gender. ANCOVA is a linear statistical model with one continuous outcome variable and one or more factor variables. It can be used to test if certain factors have an effect on the outcome variable after removing the variance for which the covariates account [22].

ANCOVA is used to increase power of the analysis of variance (ANOVA) by adding a second or third variable as a covariate. Similar to other statistical procedures, ANCOVA makes some assumptions about the data being analyzed and only when these assumptions are met will valid results be produced. Usually, ANCOVA assumes that the errors are normally distributed and the relationship of the dependent variable to the independent variables must be linear in the parameters.

The independent terms in this study were the teaching method and student gender, and the dependent term was the learning effectiveness of "Aquatic Life." This study divided the test questions into three different categories: memorization, comprehension, and critical thinking, and the score for each type of questions could also be used as a dependent term to further investigate the improvement of students' learning in a certain type of ability. The covariant term was students'

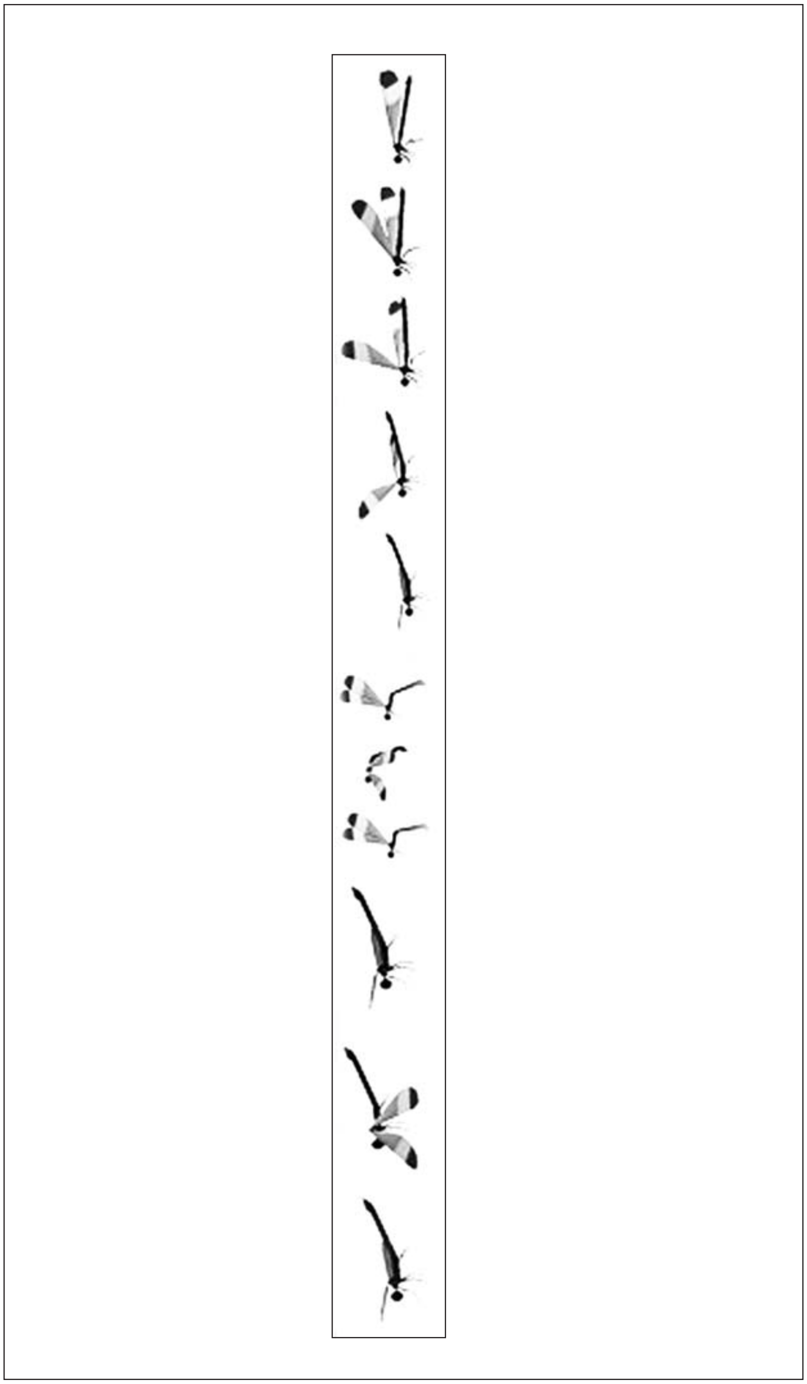

Figure 6. The damselfly's three sets of motions (flying, touching water surface, and stopping at a plant).

possessed knowledge in "Aquatic Life," which was measured by the pretest before the classes began. Finally, the controlled variables were teacher, class length, and learning contents. During the experiment, both groups were taught by the same teacher for the same number of hours using the contents designed in this study.

3.2 Evaluation Tools

The evaluation tools were developed based on the teaching materials of "Aquatic Life" and there were originally 62 questions. By removing the improper questions according to the analyses of difficulty, differentiation, expert validity and content validity, 38 questions (13 true/false questions, 18 multiple-choice questions, and 7 short-answer questions) were left for usage in the pretest and posttest, of which the two-way specification table is shown in Table 1. The achievement test contained three types of questions, i.e., memorization (M-type), comprehension (C-type), and critical thinking (T-type), and the purpose was to find out the learning effectiveness in "Aquatic Life" and these three types of knowledge as well. The achievement test had a high internal consistency with the value of Cronbach' $\alpha = 0.8$ and the reliability for the three subscales were calculated as 0.65, 0.61, and 0.68, respectively.

A questionnaire survey was designed to obtain the responses of students after using the virtual ecological pond, and the results could be used to improve the system design. The questionnaire used a 5-point Likert scale to evaluate the instructional design according to its learning contents and the major features of virtual ecological pond. The objective was to understand students' reaction and feedback after using the virtual ecological pond. The questionnaire was designed according to the principles of quality assessment in children's learning websites [23], and it contained 15 questions belonging to five categories, that is, website contents, user interface design, features of multimedia, special functions, and applicability.

Table 1. The Two-Way Specification Table of Achievement Test

Type	Memorization	Comprehension	Critical thinking	Total	Percentage
True/False	3	7	3	13	34.2%
Multiple choice	8	4	6	18	47.3%
Short answer	1	5	1	7	18.4%
Total	12	16	10	38	100%
Reliability	0.65	0.61	0.68	0.80	

To ensure the reliability of the questionnaire, the science teacher and five students (non-participants in the teaching experiment) were asked to fill out the questionnaires and provide some comments after the pilot test. The questionnaire was revised according to their comments and then used in the practice teaching, with Cronbach's $\alpha = 0.85$ in the reliability analysis.

This study also conducted a qualitative research to realize students' opinions about the virtual ecological pond. In specific, the conveyed knowledge, visual effects, students' learning interest, motivation and users' suggestion were analyzed by semi-structured interviews and observations. The results could be used to improve its learning contents and website design.

The authors conducted several in-depth interviews with the students and each interview took about 30 minutes. The interviews were designed to match the outlines of interview guides prepared by the analysis of literature survey [24], which could be used to complement the quantitative results. Although there were specific questions and outlines for the students, they could talk freely to express their opinions on any related subjects without time limitation.

3.3 Experimental Results

The data in this study were collected from pretests, posttests, and user response surveys. After the data were collected, the authors used SPSS 12.0 for Windows to analyze statistics. Below is a description about the statistical analysis and the qualitative results.

Statistical Results on Pretest and Posttest

In order to find out the learning effectiveness of the instructional design using virtual ecological ponds, a *t*-test was used to analyze the scores of pretest and posttest to see if there was a significant improvement after the treatment. There were 38 questions in the achievement test, and each correct answer was given 1 point. Table 2 shows the *t*-test results of achievement test for control and experimental groups. According to the statistical results, both groups improved significantly after the treatments and the experimental group performed slightly better than the control group.

ANCOVA Results

This experiment used a one-way ANCOVA to analyze whether a significant difference was caused by using different teaching methods. According to the theory of covariant analysis, the homogeneity of within-group regression slopes had to be examined first to see if the assumption of statistic equivalence was met. The test results on the regression coefficients were calculated as $F = 0.91$ and $p = 0.34 > 0.05$, showing no significant difference between samples and thus the regression slopes for these two groups were similar, matching the assumption and thus can be analyzed by ANCOVA.

Table 2. The *T*-Test Results of Achievement Test Scores for Control and Experimental Groups

Group	Pretest Average	Pretest *SD*	Posttest Average	Posttest *SD*	Degree of freedom	*T*	Significance
Experimental	20.52	4.04	30.06	4.04	30	10.39	$p < 0.001$
Control	21.71	3.79	29.65	4.16	30	7.74	$p < 0.001$

From the analysis of independent term (teaching method) and covariant term (pretest score), it can be seen in Table 3 that the influence of independent term on the dependent term is not significant, showing the teaching methods did not cause a significant difference in the scores of posttest. According to the *t*-test results in Table 2, both groups had significant improvement in their posttests. Therefore, the instructional design using the virtual ecological pond and the instructional media of PowerPoint and video can both improve students' learning in "Aquatic Life."

Student Gender on Learning Effectiveness

In this study, the authors would also like to investigate the influence of student gender on learning using different teaching methods. The research problem involved two independent terms (teaching method and student gender), one dependent term (posttest score), and one covariant term (pretest score). According to the statistical results of a two-way ANCOVA in Table 4, it can be seen that $F = 0.23$ and $p = 0.63 > 0.05$, showing no significant difference in the learning effectiveness caused by student gender.

Teaching Methods vs. Different Types of Knowledge

In this study, the questions in the achievement test were designed to contain three types of knowledge, i.e., memorization (M-type), comprehension (C-type), and critical thinking (T-type), and the purpose was to find out the learning effectiveness of these two teaching methods on the three types of knowledge. The results in Table 5 shows that the learning of M-type knowledge was not affected by the teaching methods ($F = 1.41$, $p = 0.24 > 0.05$). For C-type knowledge, there was no significant difference between these two groups of students ($F = 0.39$, $p = 0.53 > 0.05$). However, the result of T-type knowledge ($F = 3.87$, $p = 0.05$) has just reached the significant region, indicating the usage of virtual ecological pond as a teaching tool can enhance the ability of critical thinking.

Table 3. Statistics Results Using a One-Way ANCOVA

Source	Type III Sums of Squares	*F*	Significance
Teaching method	4.54	0.26	0.61
Pretest score	10.60	0.61	0.44

Table 4. Statistics Results of Student Gender on Learning Effectiveness

Source	Type III Sums of Squares	*F*	Significance
Pretest	12.28	0.68	0.41
Gender	2.48	0.14	0.71
Method	5.55	0.31	0.58
Gender*Method	4.14	0.23	0.63

Table 5. The Learning of Effectiveness on Three Types of Knowledge by Two Teaching Methods

Source	Type III Sums of Squares	*F*	Significance
M-type knowledge	0.32	0.10	0.75
Teaching method	4.44	1.41	0.24
C-type knowledge	0.48	0.13	0.72
Teaching method	1.50	0.39	0.53
T-type knowledge	0.53	0.23	0.64
Teaching method	9.00	3.87	0.05

According to the authors' inference, the difference could be resulted from the fact that watching video and PowerPoint slides was a passive learning process such that students received knowledge by memorizing what they had seen. This might be the reason why they didn't have enough critical-thinking skills for judgment when answering T-type questions. On the contrary, students in the experimental group had the experiences of exploring and interacting in the virtual ecological pond, so they were able to understand the relationship between obtained knowledge and learning situations, which could help them to internalize knowledge. When students encountered the problems requiring critical thinking, they only needed to remember what they had seen and done in the virtual ecological pond to make a correct judgment.

Because of the limited scope of the teaching materials implemented in this study, and only two classes in the same school were experimented, the statistical test results might not reflect the large-sample scenario. For example, if there were more species of aquatic animals and plants or the test questions were at different difficulty levels, M-type and C-type knowledge might show significant differences between these two teaching methods. After playing the game of removing Pomacea canaliculata and sponges, students could understand the influence of dominant species and foreign species on an ecological system. It would be easier for them to answer more difficult questions about ecological protection. The results could also be different if a delay test was given one or two months later. Because the learning experience in virtual ecological pond was more interesting and realistic than that of watching PowerPoint slides and video, the former could help students to develop and internalize their knowledge for future applications.

Summary of Questionnaire Results

After the classes, students in the experimental group were asked to fill out the questionnaires and the cumulative results of the answers were calculated to analyze their attitudes toward the virtual ecological pond. The questionnaire results in each category are summarized as following:

- Website contents

  Most students (92%) thought the virtual ecological pond was interesting and helpful in presenting the information about aquatic plants and animals. Students were eager to express their opinions during the class, and they would combine their possessed knowledge with the learning experiences in the virtual ecological pond to interpret the scientific meaning of acquired knowledge.
- User interface design

  Most students (87%) felt the virtual ecological pond easy to use, but some students were not familiar with the control of their movement using keyboards. 84% of the students considered the information on the website well organized and easy to read. Some students had the feeling that the download speed was not fast enough, which might be due to a lot of users connecting to the website at the same time.
- Multimedia design

  Most students (87%) found the models of aquatic plants and animals realistic and the virtual ecological pond very close to natural environments. 80% of the students thought they could observe and operate easily in the virtual ecological pond, and they believed it was more effective in improving students' critical-thinking ability than using PowerPoint slides and video as instructional media.

- Special functions

  Most students (97%) agreed that removing the eggs of Pomacea canaliculata and sponges was interesting and effective to enhance the concepts of ecological conservation, and they could receive positive feedback from the game-based learning activities, which provided a deep impression about the influence of foreign species and dominant species on aquatic ecology.
- Applicability

  Most students (87%) felt learning in the virtual ecological pond more interesting and convenient than that in a real ecological pond, and they also received more information about aquatic plants and animals from the virtual ecological pond, which was very helpful in learning aquatic life.

Observation and Interview Results

According to the interview transcripts and observation recording, the opinions of students about the virtual ecological pond were collected and classified into the following categories: knowledge conveyance, visual effects, learning interest, and motivation, users' suggestions.

- Knowledge conveyance

  Students thought there was abundant information in the virtual ecological ponds. They could see many kinds of aquatic plants and animals, including some species rarely found in their campus. Students were very excited since they could dive into water to see some aquatic insects and fishes swimming around the submerged plants. They felt the way of clicking on the aquatic plants or animals to show the information very useful because it could enhance their knowledge about aquatic life.
- Visual effects

  Many students considered the simulation of aquatic animals' motions realistic, but some students suggested the simulation of some insects' motions required further improvement. Since the aquatic insects were moving around under or above the water, it would take some time to discover their locations. Students often stayed together to help each other in finding their targets. They thought the contents of virtual ecological pond were more interesting and realistic than that of PowerPoint slides or video.
- Learning interest and motivation

  After showing them how to use the virtual ecological pond, most students couldn't wait to operate by themselves. According to the observation, many students concentrated their attention on the monitor since they had never seen this kind of educational websites and it was very interesting. They thought the design of "virtual channel" very convenient for observing underwater ecology. Many students were interested in playing the game of removing Pomacea canaliculata and sponges, showing the way of game-based learning greatly increased students' interest and learning motivation.

- Users' suggestions

  Many students felt the virtual ecological pond easy to use, and only a few students were not familiar with the operation of keyboard for the control of their movement. For example, a few students only used directional keys to control the movement and forgot that they could also use "Page Up" and "Page Down" keys to control the viewing angle. In that case, they might not be able to find some of the aquatic plants or animals specified by their teacher and this became a learning obstacle.

4. CONCLUSIONS

An ecological pond is an artificial pond to imitate an ecological environment where many aquatic plants and animals coexist to achieve a balanced ecological system. To maintain the ecological balance, the ecological pond must be well constructed to satisfy the conditions of pond bottom and varieties of aquatic plants and animals. Besides, it also requires a water-circulating system and suitable maintenance. Many schools can not meet these requirements due to limited manpower and resource, so the development of a virtual ecological pond can solve the difficulty of unable to build an ecological pond. Further more, the interactive learning situations in the virtual learning environment can also make up for the deficiency of traditional teaching methods in elementary science education.

According to the experimental results, students in both groups had significant improvement in learning "Aquatic Life" after the treatments, indicating both teaching methods could enhance students' learning. Although there was no significant difference between these two groups in their learning effectiveness, the experimental group performed better than the control group in learning T-type knowledge, indicating the instructional design using virtual ecological pond can improve students' critical-thinking ability. However, student gender had no influence on learning effectiveness in either group.

In spite of the statistical results, using the virtual ecological pond has some advantages over traditional teaching methods. For example, there are abundant learning contents in the virtual ecological pond, so it can save the time and efforts of teachers in preparing teaching materials. Besides, students can also learn on the website through networks by themselves and thus it is very useful to apply the virtual ecological pond in science education. Nowadays, the teaching materials of natural science in elementary schools are focused on the observation of common plants and animals in daily life, and the virtual ecological pond provides an easy and efficient way to observe aquatic life.

The results of questionnaire survey showed that most students felt the virtual ecological pond interesting, easy to use, and close to natural environments. They could obtain a lot of information regarding aquatic plants and animals and thus it was helpful in learning aquatic life. In addition, the game of removing Pomacea canaliculata and sponges made a deep impression on students about the influence of dominant species and foreign species on an ecological system, which increased their interest and motivation in learning the concepts of ecological conservation.

The observation and interview results also showed the 3D visual effects and interactive user interface in the virtual ecological pond provided students with learning situations where they could actively explore to discover new knowledge. They could also observe from different positions and viewing angles while manipulating the system to obtain useful information and experience. Hence, the instructional design using virtual ecological pond conforms to the pedagogical theories of situated learning and "learning while doing," and thus it could enhance students' problem-solving skills.

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