Instructional Design Using the Virtual Ecological Pond for Science Education in Elementary Schools

Wernhuar Tarng, Wen-Shin Tsai, Yu-Si Lin, and Chen-Kai Shiu

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. Hence, many schools do not have the ability to build 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 school students can actively explore in the virtual ecological pond to observe aquatic animals and plants and learn about the concept of ecological conservation. A teaching experiment was conducted to investigate the learning effectiveness and practicability of this instructional design, and the results showed that students improved a great deal in learning about aquatic life. They found the virtual ecological pond interesting, easy to operate and helpful to understanding the aquatic ecological system. Therefore, it is useful in elementary science education.

Keywords—Virtual reality, virtual ecological ponds, situated learning, instructional design, science education.

I. INTRODUCTION

MINISTRY of Education, Taiwan proposed in 2001 [1] that environmental education is about the interaction between people and their environments and it should 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, 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 be able to establish environmental values, develop their independent thinking and problem-solving skills and take part in creating and improving a sustainable campus [2].

The learning objectives of environmental education emphasize reflecting real life to enhance students' skills and experiences in their environments, which increases the value 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, operate, and conduct experiments. Teachers and students together can cooperate in the establishment, management and maintenance of the ecological garden, and this creates a sense of identification and belonging. Also, Luo proposed in his study [3] that incorporating actions and daily experiences into learning can improve students' ability in solving real-life problems.

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

The idea of using ecological gardens in science education 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 in teaching students about environmental protection and ecological conservation in a real campus environment by allowing these important concepts to be realized.

In addition, topics about aquatic life are common in the natural science curriculum of elementary schools. For example, "The Existence of Water in Our Environments" in Grade 1-2, "The Appearance and Characteristics of Aquatic Animals and Plants" and "Observing Animals Through Breeding" in Grade 3-4, and "An Introduction to Population" and "Ecological Conservation" in Grade 5-6. An ecological pond not only provides teachers with abundant teaching materials and a safe and economical outdoor teaching environment, but also improves their teaching skills and gives students a concrete and practical learning environment [8].

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A. Ecological Ponds

In recent years, experts and scholars have engaged in researches about ecological ponds. A research report released by the Ministry of Interior in 2005 stated that "An ecological pond is an ecological system in the city or countryside that possesses an ecological chain and suitable climate; the pond should have sufficient area, reasonable depth, suitable 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 animals and plants can coexist and live with very little human assistance."

Ministry of Education, 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% frequently used ecological ponds in teaching [9]. It is apparent that the importance and usage of ecological ponds has increased based on the needs of natural science education in elementary schools. However, in addition to a suitable environment, a great deal of labor and resources are also required for the design and construction of an ecological pond to meet the requirements of science education. 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 Grade 1-9 Science and Technology Curriculum", the construction of an ecological pond is helpful to science education, and it also reduces the teacher's workload in preparing for class. Because many schools do not have the manpower and resources to construct, manage and maintain an ecological pond, it would solve these problems if one could build a virtual ecological pond for applications in science education. In the meanwhile, students can also observe and learn through the Internet using the virtual ecological pond conveniently.

B. Virtual Reality

Virtual reality is a technology to simulate our real environments by computer graphics techniques to create 3D visual effects. Together with stereo sound effects and other sensory interfaces, users can see, hear, and feel in the virtual scenes as if situated in the real world, and even interact with the virtual environment. Virtual reality can simulate the phenomena in the real world and display some concepts and experimental procedures which are difficult to present or observe. It can also create a learning environment to match the teaching requirements and stimulate human brain's learning activities while helping students obtain knowledge and understand the meaning of abstract concepts and principles [10].

Virtual reality can be used to present educational information in visual and tangible manners instead of abstract text and symbols [11]. In a virtual environment, students can observe from different angles and interact with the environment in a different way. The diverse and correlative observation angles make a deep impression on users. With the design of further interactive functions, the virtual environment can provide students with more natural and intuitive learning experiences [12].

Three major factors are essential for the creation of virtual reality: Interaction, Immersion, and Imagination, often called the 3I features of virtual reality [13]. These factors entirely determine the virtual world, and provide an important standard for evaluating the quality of a virtual reality system. Since modern technologies paved the way for the development of virtual reality, many scholars have started to investigate the influence of virtual reality on education. For example, Taylor and Disinger [14] studied the feasibility and acceptability of applying virtual reality in environmental education, and they discovered that virtual reality provided students with many experiences not available in real life, hence it was very helpful to learning.

This study combined virtual reality technology with the instructional design in "Aquatic Life" learning unit in the natural science curriculum of elementary schools to create a web-based virtual ecological pond to solve the problem that many schools cannot build real ecological ponds for using as teaching resources. Students can visit the website to learn about the aquatic animals and plants in the virtual ecological pond. The virtual ecological pond was built inside a beautiful schoolyard where one can see many flowers, plants, and trees commonly exist in campus; there are also many aquatic animals and plants in the ecological pond. Students can control their viewing angles and positions, and even dive into the ecological pond to observe different types of submerged aquatic plants, aquatic insects and fish. They can also play the games of removing Pomacea canaliculata and sponges to understand the influence of dominant species and foreign species on an ecological system.

C. 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 and living environments, and scientific researches so that students can observe, interact with, and solve problems in a real or virtual environment to encourage their cognitive and learning requirements.

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

Situated learning considers daily-life situations as a part of the learning experience, hence specialization of learning situations and interaction between learners and situations are important issues in this research area. Many educators recognized the importance of situated learning, so they started to walk out of laboratories and enter actual teaching and living environments to conduct their practical researches.

Burner [15] believed that learning activities involving discovery or creation could provide students with the ability to

develop, induce, and apply their knowledge and understand its meaning. Brown, Collins and Duguid [16] also believed that learning should exist within learners and environments. In natural science education, students' living environments form the background of learning and real-life problems should be the center for students to develop their own knowledge. In this way, students can build up meaningful scientific knowledge and apply it to solving practical problems. This is the concept of learning based on the needs of real life, emphasized by many science education researchers [17].

There are at least three functions when applying real activities to teaching: (1) Learners can understand the connection between knowledge via teaching activities. (2) Learners can anticipate opportunities to apply knowledge and understand the effects of applying knowledge in solving a problem, which also provides a motive for learning. (3) Learners can actually apply their knowledge through learning activities. Learners often acquire more knowledge in the process of applying it, and naturally understand the relationship between acquired knowledge and the situation in a problem. As a result, their prior knowledge is more likely to be applied in the future when they encounter a similar problem [18][19].

Computer simulation is frequently used in situated learning with phenomena that cannot be expressed in its original form, for instance: chemical reactions, animal reproduction, and volcanic eruptions. However, computer simulation without interaction causes learners to merely watch and marvel at the superficial appearance, without internalization or cognitive assimilation. Hence, if virtual reality is used to create a social situation, learners are able to manipulate some variables to observe the results and then correct their behavior accordingly to learn some 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 [20].

D. Research Objective

A virtual ecological pond provides students with a learning environment to simulate real situations, in which they can observe, operate and experience through online learning activities under the guidance of teachers. In the meanwhile, they can also relate these experiences to the real world for future practice. Under the framework of situated learning theory, this study used virtual reality to develop a virtual ecological pond based on the teaching plans and strategies of the "Aquatic Life" learning unit in the natural science curriculum of elementary schools, allowing students to observe aquatic animals and plants through network exploration. The objective was to solve the problems of building and managing a real ecological pond as a teaching tool in elementary schools.

To enhance the functions of assisted learning, the virtual ecological pond displayed many types of aquatic animals and plants and provided the related information for immediate reference. Students could use the control keys and mouse to move around and switch their viewing angles above and under the water. A game-based learning activity was designed to remove the eggs of Pomacea canaliculata and sponges. The system provided instant feedback through an interactive mechanism to emphasize the influences of foreign species and dominant species on an ecological system. Students could experience the fun of "learning while doing" at the same time when developing the concepts of ecological conservation.

This study was divided into two parts. The first part included instructional design and system development; the second part included system evaluation and a teaching experiment. At first, the teaching materials of "Aquatic Life" was analyzed and then the software 3ds Max, Photoshop, and Virtools were used to develop the virtual ecological pond. After the system was completed, a teaching experiment was conducted to investigate the learning effectiveness and practicability of the virtual ecological pond. A questionnaire survey was also used to collect the data about students' responses and feedback after using the virtual ecological pond. The experimental results can be used as a reference for the improvement of the system in the future.

II. RESEARCH METHODS

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

A. Analysis of Teaching Materials

At the beginning, the teaching materials of "Aquatic Life" in the natural science curriculum of elementary schools and the learning contents from several textbooks about ecological ponds were analyzed to determine the learning objectives of the instructional design for this study, which are listed in the following:

1. To know different aquatic environments
   - Various aquatic environments in our surroundings
   - The characteristics of aquatic environments
2. 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.
3. To identify aquatic animals
   - The fish, aquatic insects and amphibians
   - The insects near the aquatic environments
4. To recognize the characteristics of aquatic animals
   - Aquatic animals move or swim using different parts of their bodies.
5. To care about the ecological pond
   - Protecting the environment of the ecological pond
   - Understanding the influence of dominant species on the

ecological pond
● Don't abandon animals in an ecological pond.

According to the analytical results, the virtual reality technology was used to build a virtual ecological pond, and the game-based learning theory was used to design the learning activities about foreign species and dominant species to increase students' interest and strengthen the concepts of ecological conservation.

B. System Design

In this study, the authors combined the instructional design of "Aquatic Life" learning unit with virtual reality and network technologies to create a virtual ecological pond for applications in elementary science education. Due to the number and variety of animals and plants, it was important to use simpler structures and smaller images when designing the virtual scenes and the models of aquatic animals and plants for the reduction of file size and computation time. The design of virtual ecological pond and the creation of 3D models for aquatic animals and plants are described in the following, together with an introduction to the user interface of the website and its learning contents.

1. Virtual Ecological Pond

The virtual scenes developed in this study includes: a schoolyard and two ecological ponds. The campus of Hsinchu Elementary School, Hsinchu was referred to in the design of virtual scenes to create a realistic situation for the induction of more concrete learning and cognition. After entering the virtual schoolyard, students could see a long row of classrooms with tall palm trees and Juniperus chinensis in front of them. There were also many golden dewdrops and banyan trees in the green grass. The design of virtual ecological pond was based on the floor plan of the ecological pond at Shuanglian Elementary School, Shilin (Figure 1), which uses recycled rainwater drawn into an artificial ecological environment, with pathways around the pond so that students can observe aquatic animals and plants at a close distance.
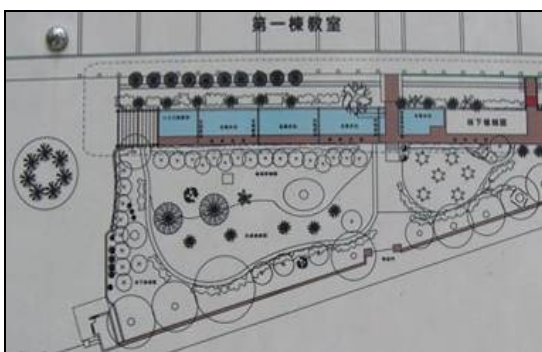

Fig. 1 The floor plan of the ecological pond at Shuanglian Elementary School, Shilin

The ecological pond is the most important part inside of the virtual schoolyard, and is also the home of aquatic plants, aquatic insects, fish, shellfish, and amphibians. In order to present the diverse species of aquatic animals and plants, there were two ecological ponds developed and aquatic animals and plants were divided separately into these two ponds according to their habitual behavior. Basically, both ecological ponds contained emergent, submerged, free floating and rooted floating plants. Aquatic animals were equally distributed in these two ecological ponds to show the situation of an abundant and ecologically balanced environment.

According to the above plan, the virtual schoolyard was designed using the pictures of Hsinchu Elementary School as texture images. A wall was constructed to limit the walking area within the schoolyard and prevent students from wandering away. There were palm trees, banyan trees, Juniperus chinensis, and golden dewdrops in the schoolyard to create the feeling of being in a realistic campus while increasing students' knowledge about common plants (Fig. 2).

Fig. 2 The virtual schoolyard developed in this study

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

Fig. 3 The underwater view of virtual ecological pond

Two red triangular cones were placed at the shore and bottom of the ecological pond as the switches to pass through the "virtual channel" (Fig. 4). By clicking on the triangular

cone, students could change their current positions such that they could dive into or flow above the water to observe aquatic animals and plants. 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" solves the problem of observing underwater ecology in real life.
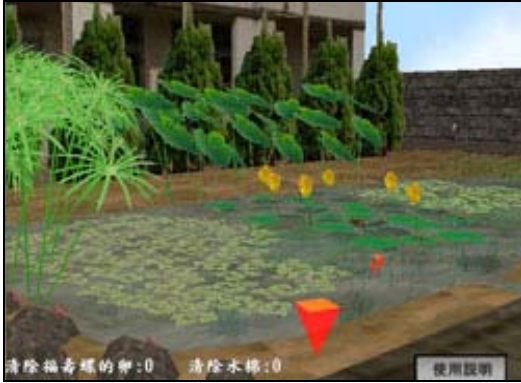

Fig. 4 Diving into the pond via the "virtual channel"

2. Aquatic Plants

Aquatic plants generally refer to plants living in the water, and they are different from land plants since they rely on water more. While 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 the 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, and both ponds had four types of aquatic plants. Usually, emergent plants grow on the edges of ponds, for example, Schoenoplectus mucronatus, Cyperus alternifolius, Colocasia esculenta, Typha latifolia, and Hydrocotyle vulgris. Rooted floating plants grow in the water with leaves floating on the water surface, for example, Nuphar shimadai Hayata (Taiwan's indigenous species), Trapa maximowiczii Korsh, and Marsilea. Submerged plants grow at the bottom of the ponds, 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, e.g., Azolla, water cabbage, and duckweed.

The procedure for developing virtual aquatic plants includes: determining species, designing texture images, creating models, reducing the number of images, and duplicating the aquatic plants. An introduction to each step is described as follows.

(1) Determining species

There are thousands of vascular plants in Taiwan, and aquatic plants take up merely over 300 of them. Those species categorized as aquatic plants include the majority of indigenous species and a few types of aquatic plants brought in for gardening and aquarium. A lot of time was spent in collecting data about aquatic plants by observing the ecological ponds at Shuanglian Elementary School, Sanmin Elementary School, Songshan Fumin Park, and Gongguan Elementary School. The authors also studied the aquatic plants appearing in the natural science curriculum of elementary schools to find out the most common species in Taiwan.

(2) Designing texture images

In the process of creating a 3D model, an important step is designing and pasting texture images for which can decide the file size and how realistic the model looks. When taking a picture, the plant must be clear without being covered by other objects. A cut-out image and its mask image can be obtained after using Photoshop to remove the background of the original image and obtain the required region (as seen in Fig. 5).

Fig. 5 Designing texture images: original image (left), cut-out image (center), mask image (right)

(3) Creating 3D models

There are two different approaches to creating the models of aquatic plants, depending on the shape and complexity of the models. For example, The unique appearance of Cyperus alternifolius requires the more traditional modeling method, but one important thing is not to use too many points and facets in the model. For example, the Cyperus alternifolius in Fig. 6 has 276 points and 302 facets. In this study, most aquatic plants were limited to have less than 300 facets to reduce the download and computation time. Another method is to use the crossed-section texture mapping. For example, Pistia stratiotes have complex fibrous roots, so using the traditional modeling method may create too many points and facets, which can be reduced by pasting the root images on two intersecting planes.

Fig. 6 Traditional modeling (Cyperus alternifolius) vs. crossed-section texture mapping (Pistia stratiotes)

(4) Reducing image size

The numbers of points, facets, and the resolution of images are the major factors to decide the file size and how realistic the scene is, so the designers must make effective use of texture images to achieve the expected visual effects. For example, if each type of aquatic plant requires at least three texture images and each image is about 36 KB, then the 14 types of aquatic plants in the ecological pond will take up over

1500 KB, which may result in quite much download and computation time. In order to solve this problem, the designers used Photoshop to composite a texture image (512×512 pixels in size) that could accommodate more than 8 texture images of aquatic plants (Fig. 7). Using this approach, only five images were used (each image at about 138 KB with a total file size of 690 KB), which effectively reduced the number of images and file size.
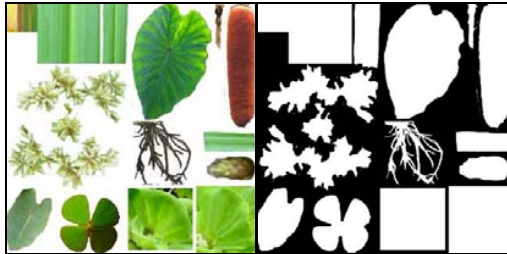

Fig. 7 A combined texture image of aquatic plants

3. Aquatic Animals

Animals in the ecological ponds mainly consists of aquatic insects, fish, shellfish, and amphibians. Among them, Pomacea canaliculata, Dytiscidae, fossil dobsons, tadpoles, Laccotrephes Macropodus opercularis, and Gambusia affinis live in water, while Gerridae, dragonfly, damselfly, and Guentheris frog live above water. Besides the aquatic insects, there are several common insects living around the ponds and on the water surface as well, for example, groups of Gerridae. They have long slender bodies and thin, grease-covered hairs on their legs, which create a waterproof effect allowing them to glide over the water quickly due to surface tension.

Dragonflies and damselflies like to live by the ponds. Therefore, one can often see them flying above the water surface or resting on the grass. "A dragonfly skimming water surface" describes the way that dragonflies and damselflies lay eggs. After mating, the female dragonfly or damselfly will fly close to the water and repeatedly tap on water surface using its tail to place its eggs in the water or on an aquatic plant.

Amphibians such as frogs play an important part in the ecological ponds. "Amphibian" means the animals inhabit two living environments. When they are young they live in water, and when they are grown they leave the water. Most grown amphibians still need to live in wet areas such that their skins will not dry. Fish are a charming rambler in water and they rely on zooplankton and insects as a source of food. Therefore, fish play an important part in the food chain and they are often called the nemesis of insects carrying diseases.

In recent years, the invasion of foreign species has threatened the living environments of indigenous species in Taiwan. For instance, Pomacea canaliculata is a foreign species that originated from human abandonment. One can often see a lot of pink egg clusters adhered to rice paddies, showing the strong reproductive ability of Pomacea canaliculata, which cause the death of aquatic plants and affect the harvest of crops because they like to eat the tender parts of aquatic plants.

The major steps of creating virtual aquatic animals include: determining species, creating models, designing texture images, adding skeletal systems and motion design. In creating the 3D models, one must consider their sizes and the resolution of texture images to reduce the file size and make the models suitable for observation. A detailed description for each step is given below.

(1) Determining species

An ecological pond is an artificial pond where the aquatic animals are released by humans. The authors had decided to breed Macropodus opercularis (a protected species), Gambusia affinis, a common species which eat the larva of mosquitoes, and some other common aquatic animals, including six insects (dragonfly, damselfly, Dytiscidae, laccotrephes, fossil dobsons, Gerridae), an amphibian (Guentheris frog and tadpoles), and a shellfish (Pomacea canaliculata, for teaching the topic of invasion by foreign species).

(2) Creating 3D models

When creating the 3D models, one must make sure that all animals have a proportional scale and then use 3ds Max to create the models according to the pictures of aquatic animals. Although a hand-drawn model is not as detailed as obtained from a 3D digital imaging system, it has fewer points and facets and therefore can save the computation time when simulating the motion.

(3) Designing texture images

The texture images of aquatic animals must be pasted on the surfaces after the 3D models were created. When designing texture images, the photos of aquatic animals were scanned into suitable sizes, and then Photoshop was used to remove the background. Finally, the UVW Map function of 3ds Max was used to paste the image to the surface of the model (Fig. 8), and then the Unwrap UVW function was used to adjust the position of image. The resolution of texture images affects both the sense of reality and the file size. A high-resolution image can create a more realistic model, but the larger file size can also increase the download and computation time.

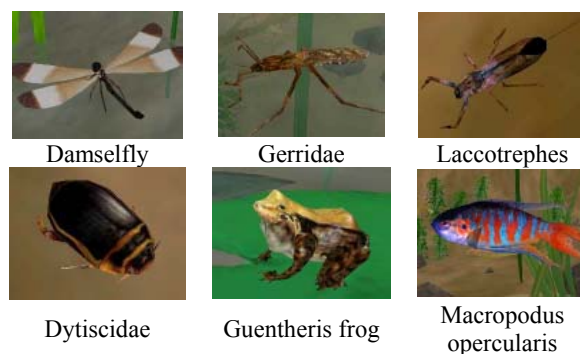| Damselfly | Gerridae | Laccotrephes |
| Dytiscidae | Guentheris frog | Macropodus opercularis |

Fig. 8 The aquatic animal models with texture images

(4) Adding the skeletal system

The coordinate system of an aquatic animal model must be reset as soon as created using the Xform function to insure that the model would not be distorted after exported to Virtools. When adding a skeletal system to the major parts of an aquatic animal model such as head, body, wings, feet (or fins, tails), it is important to make proper connection between the skeleton and the model. In the meanwhile, one has to be careful in setting the area of influence by the skeleton or it may result in serious distortion when the model is in motion.

(5) Motion design

In order to enable the created model to move freely and lively in the virtual ecological pond, the designers simulated the motions of aquatic animals by analyzing their behavior based on some reference books and video programs. To avoid discontinuity during the transition between different motions, the designers had to make sure that the starting and ending frames of all motions were in the same attitude. For simplicity, the motions designed in 3ds Max were set to a fixed position while the rotation and movement in the virtual scene were controlled by the programs in Virtools. For example, a damselfly has three sets of motions, include flying above the water, toughing the water surface, and stopping at a plant (Fig. 9). These three sets of motions have different probabilities of occurrence, and the condition for a state transition to occur is whether the dragonfly touches water surface or aquatic plants.
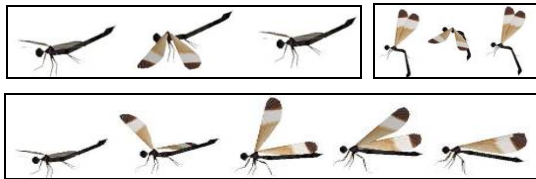

Fig. 9 The damselfly's three sets of motions (flying, touching water surface, stopping at a plant)

Motion design in Virtools can be done by using the functions of Building Block, and each building block is used to create an interactive user interface or a behavior model. A more complicated behavior model can be created by combining several building blocks (Fig. 10). For instance, when the damselfly flies, the designers must set a random timer on the damselfly model so that within a fixed period of time the damselfly continues to fly back and forth, and once the time is passed, it will be rotated by a certain angel and continue the same process. When the damselfly touches the water or a plant during flying, the building block will activate the script of "touching the water surface" or "stopping at a plant" and then continue the next behavior model.
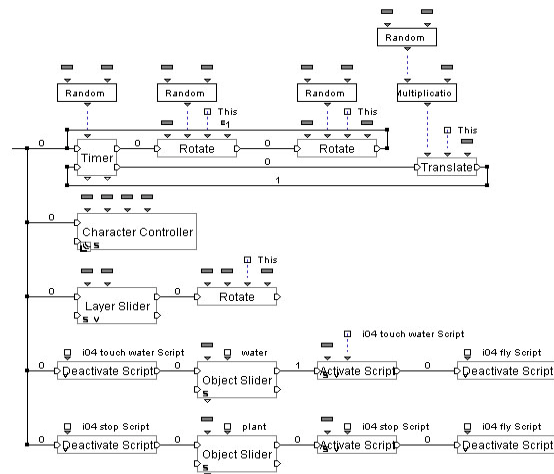

Fig. 10 The design of damselfly's flying motion

4. Website Contents and User Interface

The learning contents on the website developed in this study include: the virtual scene of ecological pond and the webpages containing information about aquatic animals and plants (Fig. 11). Students can visit the virtual ecological pond through the Internet, and click on the links to read about the related information. For easy navigation, the homepage contains the links of "free floating plants", "submerged plants", "rooted floating plants", "emerging plants", "aquatic animals", "aquatic insects", "others", and a music player (to play the sounds of Guentheris frogs). In addition to introducing in detail the features and living environments of aquatic animals and plants, these webpages also provide many pictures of aquatic animals and plants in virtual and real ecological ponds for comparison to provide a connection between knowledge and learning situations for students.

Fig. 11 The website of the virtual ecological pond

After entering the virtual ecological pond, users can control their moving direction using arrow keys on the keyboard: forward (↑), backwards (↓), turn left (←), and turn right (→). For easy observation, they can also use "Page Up" and "Page Down" keys to control the viewing angle. To increase reality and interaction, the designers adopted a first person camera mounted on a movable 3D frame. The 3D frame was attached to the ground like users' feet and the height of the camera was

about that of a child. Users can also use the mouse to remove the eggs of Pomacea canaliculata, or change their positions above and below the water by clicking on the triangular cones. In addition, if users have difficulties, they can click on the link of "user manual" for immediate help.

In the submenu of "others", users can find the link of "course design", which provides reference material for instructors using the virtual ecological pond as teaching materials. Clicking on the link of "contact us" will automatically activate Microsoft Outlook and users can send an email to the system manager and wait for the answer when they have questions.

III. Teaching Experiment

In this study, a teaching experiment was conducted to investigate the effectiveness of instructional design using virtual ecological pond for "Aquatic Life" learning unit in elementary schools. In addition, the authors would like to receive feedback from teachers and students after they used the virtual ecological pond. A description about the experimental design, research tools, data processing, and analysis of results is given below.

A. Experimental Design

This study randomly selected two classes of third grade students (31 students in each class, with a total of 62 students) from an elementary school at Hsinchu as samples. The classes were coeducational and arranged by the policy of normal grouping. One class was assigned as the experimental group and the other was assigned as the control group. The former adopted the instructional design using virtual ecological pond as a teaching tool, and the latter adopted traditional teaching method using PowerPoint and video as instructional media.

To understand if the virtual ecological pond can help students in learning the knowledge of aquatic life and the concepts of ecological conservation, this study adopted a nonequivalent-groups pretest-posttest design to analyze if there was significant difference in learning effectiveness between these two methods. A questionnaire survey was also given to the experimental-group students to obtain their responses and feedback after using the virtual ecological pond, and the results can also be used as a reference for system improvement in the future.

The independent terms in this study were teaching method and student gender, and the dependent term was the learning effectiveness of these two methods. This study further divided 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 investigate the improvement of students' learning in a certain type of knowledge. The covariant term was students' possessed knowledge in "Aquatic Life", which was measured by the pretest before they attended the class. Finally, the controlled variables were teacher, class length, and learning contents. Both groups were taught by the same teacher for the same time using the same contents designed in this study.

B. Research Tools

This study used self-edited teaching materials for the learning unit of "Aquatic Life," as well as the virtual ecological pond, learning website, achievement test, and questionnaires as research tools.

1. Teaching Materials

To maintain the consistency of teaching materials for both groups of students, we revised the contents on the website of virtual ecological pond to create the teaching materials of "Aquatic Life" for the control group. The only difference was that the virtual ecological pond was used as a teaching tool in the experimental group while PowerPoint and video were used as instructional media in control group. Both groups were taught using the same teaching materials, including common aquatic plants and animals, and the issues like foreign species and dominant species in Taiwan, to increase the consciousness and awareness of students about aquatic life and ecological conservation.

2. Virtual Ecological Pond

A virtual ecological pond was developed in this study to display aquatic plants and animals commonly seen in campus. Students can explore in the virtual campus to learn about aquatic life and perform the task of removing the eggs of Pomacea canaliculata and sponges to become aware of dominant species and foreign species and their influence upon ecological systems.

3. Learning Website

The teachers used the learning website to introduce aquatic plants and animals in the ecological pond and the contents included the detailed information (such as the species and scientific names) and an introduction to their living environments and characteristics.

4. Achievement Test

This study developed its evaluation tools based on the teaching materials of "Aquatic Life". There were totally 38 questions in the pretest and posttest after removing the improper questions according to the analyses of difficulty, differentiation, expert validity, and content validity with Cronbach's $\alpha=0.8$.

5. Questionnaire Survey

After the class, students in the experimental group had to fill out a questionnaire and the data were used to analyze their responses and feedback after using the virtual ecological pond. There were five categories in the questionnaire, including webpage contents, user interface, multimedia design, special functions, and practicability. The results can also be used as a reference for system improvement in the future.

C. Data Processing

After collecting data from the pretest, posttest, and questionnaire survey, the authors used SPSS 12.0 for Windows to analyze the data to obtain the experimental results. The statistical methods used for analyzing the data are described in the following.

1. Reliability Analysis

The internal consistency between both groups was calculated using the coefficient of Cronbach α to ensure the reliability of evaluation tools.

2. T-Test

Because the average scores of pretest and posttest for the experimental group and control group were correlated data, a t-test for dependent samples was used to examine whether a significant difference was achieved between the average scores of the pretest and posttest.

3. Analysis of Covariant

An ANCOVA was used to investigate the difference in learning effectiveness between the experimental group and control group as well as the variance between boys and girls. The same method was also used to find out the learning effectiveness on the three types of knowledge by these two teaching methods.

4. Cumulative Results

The cumulative results of students' answers in the questionnaire survey for the experimental group were calculated and analyzed after the experiment.

D. Analysis of Results

1. Statistical Results on the 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 evaluate 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 one point. Table I shows the average scores of pretest and posttest and their difference for the experimental and control groups. According to the statistical results, both groups improved significantly after the experiment, and the experimental group performed better (10%) than the control group.

TABLE I
DESCRIPTIVE STATISTICS ON THE PRETEST AND POSTTEST

Group	Pretest	Posttest	Difference	T-test
Experimental	20.52	30.06	9.54	10.39**
Control	21.71	29.65	7.94	7.74**

**p<.01

2. The Results of ANCOVA

This experiment used a one-way ANCOVA to study whether different teaching methods caused significant differences, where pretest was the covariant, posttest was the dependent variant, and teaching method was the independent term. According to the theory of covariant analysis, the homogeneity of within-group regression slopes was examined first to see whether the assumption of statistic equivalence was met. The test results on the regression coefficients was 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, which matches the

assumption of statistically equivalent regression coefficient within the groups and thus can be analyzed by ANCOVA.

From the analysis of independent term and covariant term in different groups of students, it can be seen in Table II that the influence of the independent term on the dependent term is not significant, showing that teaching methods did not cause a significant difference in the scores of posttest. However, both groups had significant improvement in their achievement tests. 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.

TABLE II
STATISTICAL RESULTS USING A ONE-WAY ANCOVA

Source	Type III Sums of Squares	F-test	Sig.
Method	4.54	0.26	0.61
Pretest	10.60	0.61	0.44

R^2 = 0.013 (the adjusted R^2 = -0.021)

3. Student Gender on Learning Effectiveness

In this study, the authors also wanted to investigate the gender effect on students' learning using different teaching methods. The research problem involved two independent terms (teaching method and gender), one dependent term (posttest grade) and one covariant term (pretest score). According to the statistical results of a two-way ANCOVA (Table III), it can be seen that $F=0.23$ and $P=0.63>0.05$, indicating no significant difference in learning effectiveness caused by student gender. This means that boys and girls both performed well when using the virtual ecological pond as a teaching tool in learning the unit of "Aquatic Life".

TABLE III
STATISTICAL RESULTS OF STUDENT GENDER ON LEARNING

Source	Type III Sums of Squares	F-test	Sig.
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

4. Teaching Methods vs. Different Types of Knowledge

In this study, the questions in achievement tests were designed to contain three types of knowledge, that is, 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 any of the two teaching methods ($F=1.41$, $P=0.24>0.05$). For C-type knowledge, there was no significant difference in students' learning by either of the teaching methods ($F=0.39$, $P=0.53>0.05$). However, the result of T-type knowledge ($F=3.87$, $P=0.05$) has just reached the significant region, showing that using the virtual ecological pond as a teaching tool can enhance the ability of critical thinking.

TABLE IV
COMPARING THE LEARNING EFFECTIVENESS ON THREE TYPES OF KNOWLEDGE
BY TWO TEACHING METHODS

Source	Type III Sums of Squares	F-test	Sig.
M-type	0.32	0.10	0.75
Method	4.44	1.41	0.24
C-type	0.48	0.13	0.72
Method	1.50	0.39	0.53
T-type	0.53	0.23	0.64
Method	9.00	3.87	0.05

According to the authors' inference, the difference could be resulted from the fact that watching plan media was a passive learning process through which 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. Contrarily, students in the experimental group had the experiences of exploring and interacting with the virtual ecological pond, so they were able to understand the relationship between knowledge and the 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 the right judgment.

5. Summary of Questionnaire Results

In order to understand the responses of students after using the virtual ecological pond, a questionnaire was designed using 5-point Likert scale, including questions in the following five categories: website contents, user interface, multimedia design, special functions, and practicality (as shown in Table V).

In terms of "website contents", most students thought the virtual ecological pond was interesting and helpful in presenting aquatic life. During the classes, students were eager to express their opinions, and they would combine their possessed knowledge with the learning experiences in the virtual ecological pond to interpret the scientific meaning of aquatic life.

In terms of "interface design," most students found 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, some students only used forward (↑), backwards (↓), turn left (←), and turn right (→) keys and forgot that they could also use "Page Up" and "Page Down" keys to control the viewing angle. In that case, they were not able to find the aquatic plants or animals specified by their teacher and this became a learning obstacle.

In terms of "multimedia design", most students found the appearances of aquatic animals and plants realistic and the virtual ecological pond very close to the natural environment, thus it was more convincing and effective than using PowerPoint and video as instructional media. Because the execution speed was limited by computer and network hardware, some students had the feeling that the download speed was not very fast. In general, most students were able to keep up with the pace of teacher.

In terms of "special functions", most students found removing the eggs of Pomacea canaliculata and sponges interesting and effective in strengthening the concepts of ecological conservation. Many students received positive feedback from the game-based learning activities, which also left a deep impression on them regarding the topic of the influence by dominant and foreign species.

In terms of "practicality", most students felt visiting virtual ecological pond more interesting and convenient than visiting a real ecological pond, and they also received more information about aquatic plants and animals from the virtual ecological pond, which was helpful to learning aquatic life.

IV. CONCLUSION

An ecological pond is an artificial pond to imitate an ecological environment where many aquatic animals and plants coexist to achieve a balanced ecological system. To maintain the ecological balance, the ecological pond must be well constructed to satisfy the conditions of the pond bottom, porousness, plant varieties, and other environmental requirements. Besides, it also requires a water circulating system and complete maintenance and sustainable management. Many schools can not meet these requirements due to some objective and realistic limitations, so creating a virtual ecological pond can solve the difficulty of unable to build an ecological pond. Further more, the interactive learning situations in a virtual learning environment can also make up for the drawback of applying an ecological pond in elementary science education.

It was found in the teaching experiment that using the virtual ecological pond in elementary science education had many advantages. For example, the 3D visual effects and simulation of aquatic life in a dynamic ecological system provided students with learning situations in which they could actively explore to discover new knowledge. They could also observe from different viewing angles and manipulate the system to obtain results through interactive user interface. Hence, the instructional design using the virtual ecological pond conforms to the pedagogical theories of "learning from doing", situated learning and constructivism, and it can enhance students' problem-solving skills.

According to the experimental results, students in both groups had significant improvement in learning after with the experimental group better than the control group, showing that the virtual ecological pond was helpful to learning "Aquatic Life" in elementary science education. However, the student gender did not cause significant difference in learning effectiveness in either group, showing that both teaching methods (using virtual ecological pond or instructional media) were suitable for boys and girls. As for the three types of knowledge, the experimental group performed better than the control group in learning T-type knowledge, indicating that the instructional design using the virtual ecological pond can improve students' critical-thinking ability.

TABLE V
QUESTIONNAIRE TO ANALYZE THE RESPONSES OF STUDENTS AFTER USING THE VIRTUAL ECOLOGICAL POND

Categories	Please read the following questions carefully, and select the number of answer representing your opinion for each question.	1. Very Agree	2. Agree	3. No Comment	4. Disagree	5. Very Disagree
Website Contents	1. The website contents are interesting and educational.	67.7%	25.8%	6.5%	0.0%	0.0%
	2. The website contents are helpful to understanding the aquatic ecology.	77.4%	19.4%	3.2%	0.0%	0.0%
User Interface	3. The operation of the virtual ecological pond is easy.	61.3%	25.8%	12.9%	0.0%	0.0%
	4. The design of virtual ecological pond is lively and interesting.	77.4%	19.4%	3.2%	0.0%	0.0%
Multimedia Design	5. The speed for downloading the virtual ecological pond is not too slow.	38.7%	38.7%	19.4%	3.2%	0.0%
	6. The 3D models and dynamic simulation of aquatic animals are realistic.	67.7%	22.6%	9.7%	0.0%	0.0%
	7. The 3D models of aquatic plants are realistic.	64.5%	32.3%	3.2%	0.0%	0.0%
	8. The design of virtual ecological pond is close to a natural environment.	67.7%	19.4%	12.9%	0.0%	0.0%
	9. I can walk freely in the virtual schoolyard, and thus it is more realistic and has better learning effects than plan media and video.	67.7%	29.0%	3.2%	0.0%	0.0%
Special Functions	10. Playing the game of removing the eggs of Pomacea canaliculata can increase my learning interest.	83.9%	12.9%	3.2%	0.0%	0.0%
	11. Playing the game of removing sponges can increase my learning interest.	74.2%	22.6%	3.2%	0.0%	0.0%
Practicability	12. The virtual ecological pond provides more information about aquatic animals and plants than a real ecological pond does.	58.1%	29.0%	12.9%	0.0%	0.0%
	13. The virtual ecological pond is more interesting than a real ecological pond.	54.8%	32.3%	9.7%	3.2%	0.0%
	14. Visiting the virtual ecological pond is more convenient than visiting a real ecological pond.	64.5%	25.8%	6.5%	3.2%	0.0%
	15. The virtual ecological pond is helpful to learning natural science in elementary schools.	61.3%	32.3%	3.2%	0.0%	3.2%

The results of questionnaire survey revealed that most students found the virtual ecological pond close to natural environments, easy to use, interesting in contents, and the virtual aquatic animals and plants very realistic in appearance. In addition, the game of removing the eggs of Pomacea canaliculata and sponges increased their interest in learning, and left a deep impression about the influence of dominant species and foreign species on an ecological system. Students widely believed that the virtual ecological pond was easy to use, interesting, and more informative than a real ecological pond, and thus very helpful to learning aquatic life.

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