

Design of a Virtual Ecological Pond for Motion-Sensing Game-Based Learning

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ABSTRACT

The campus ecological pond is an effective tool to assist science teaching since it allows students to obtain knowledge of aquatic biology in freshwater environments by practical observation. In this study, a virtual campus ecological pond was developed for applications in science education in elementary schools. The system integrates real ecological situations of aquatic environments into learning activities to enhance the learning interest and motivation of students. They can observe the features of aquatic plants and aquatic animals on mobile devices and understand the relation between food chain and ecological balance in aquatic ecosystems by role playing and game missions. The virtual ecological pond can save the cost and manpower needed for building and maintaining a real ecological pond, and it can also solve the problems of insufficient species and difficulty to observe under water. Thus, it is a useful assistant tool for teaching aquatic ecology in elementary schools.

KEYWORDS

Virtual Reality, Campus Ecological Ponds, Role Playing, Food Chain, Ecological Balance.

1. INTRODUCTION

In the K-12 Science and Technology Curriculum adopted in Taiwan, there are many topics relative to aquatic ecology, such as the “Aquatic Organisms” and “Aquatic Family” units in grade 4. Their main objective is to learn about the features of various aquatic habitats as well as to observe the structures and functions of aquatic plants and aquatic animals for understanding their relation to the ecological habitats. To enhance the problem-solving skills of students in scientific observation and their motivation of exploration, teachers often combine the teaching materials from textbooks with observational activities at ecological ponds. In addition, students can also become familiar with the factors affecting the growth of aquatic organisms by planting aquatic plants and rearing aquatic animals. These teaching activities can provide the background knowledge for learning advanced courses such as biological diversity and environmental protection in their future studies [1].

According to Chung’s definition [2], an ecological pond is a created ecosystem with various living organisms to simulate the natural lakes, ponds, or swamplands. Tsai [3] considered the depth of water and its flow, hydration of the soil as well as the living organisms the essential elements of an ecological pond where the rich ecosystem is formed artificially to provide the living environments for various species. The land and water resources in parks, schools, and private gardens can all be used to construct ecological ponds for serving as recreational sites and

the educational purposes. In addition, ecological ponds provide plants and animals with suitable living environments in metropolitan areas and thus have a great contribution to preserving biological diversity and protecting environments [4].

According to the investigation of ecological resources used in science education [5], 63.3% of elementary schools in Taiwan had ecological ponds and more than 60% of them used the ecological ponds for educational purposes. However, it costs additional money and manpower to construct and maintain ecological ponds, which is a major concern affecting the decision of whether or not to build an ecological pond for some schools. For those already have an ecological pond, it can be used as an effective teaching tool which allows students to obtain practical knowledge about aquatic ecology by observational activities. However, it requires dedicated personnel for maintenance to ensure the sustainability. Otherwise, the ecological pond may turn into a dirty pond filled with weeds and its ecological cycle may be destroyed by invasive or strong species.

As the advance of information technology, mobile devices such as personal digital assistants (PDA), smart phones, and tablet PCs are widely used in educational applications. Nowadays, learning activities are no longer confined to classroom teaching, and they can be done anytime and anywhere by using any devices to achieve the goal of ubiquitous learning [6]. Mobile learning refers to any forms of learning taking place when a learner is on the move or can move to a new place and still remain connected to online learning resources via wireless networks. Recently, a large number of mobile devices with powerful sensors such as the global positioning system (GPS), electronic compass, and 3-axis accelerometers have been developed to provide the information of position, time, direction, and acceleration to support the design of simulation software for applications in different areas of education [7].

Virtual reality (VR), sometimes referred to as immersive multimedia, is a virtual environment created by computer hardware and software to simulate the physical presence in the real or imagined world. In the virtual environment, one can interact with other people or virtual objects and receive information through their sense organs to create a lifelike experience. VR is an important area of research in science, education and entertainment [8]. A virtual yet close-to-real environment can avoid the danger, reduce the cost, and satisfy the requirements in training and experimental processes. VR has high interactivity and the sense of reality to enhance learning interest and motivation, so it is suitable for applications in science education.

When using VR in science education, the virtual learning environment replaces traditional teaching materials with visual, perceptual and highly interactive objects. A deeper perception is achieved by the 3D effects and the brain can be better stimulated during the learning activities [9]. The learners are able to observe from different perspectives to deepen their impressions; they can interact with virtual objects in different aspects to obtain more natural and direct experiences. Lin [10] believed that a virtual learning environment has four advantages, i.e., providing concrete and realistic learning environments, enhancing learning motivation, increasing learning effectiveness and enabling diversified expression of learning contents. Thus, it allows learners to observe and manipulate the virtual objects to support learning by doing and active exploration, which are often emphasized by science education.

The theory of situated learning considers that knowledge and skills are developed by interaction between learners and situations. Intrinsically, the obtained knowledge and skills are influenced by human activities, cultures and social connections. Also, situated learning emphasizes the learning style of gradual participation going from the edge to the inner. In other words, learners first observe, imitate, and acquire simple concepts, and finally obtain more in-depth knowledge and skills through learning situations [11]. The teaching activity based on situated learning is to obtain

practical knowledge and skills through real situations [12]. The instructional design, in all aspects, includes thinking, cognitive growth, the role of teachers, and learning assessments, which all together emphasize learning under simulated or practical situations to acquire problem-solving abilities for future applications in real life.

This study combined the VR technology and sensor functions of mobile devices, e.g., the touch screen, electronic compass, and 3-axis accelerometers, to develop a virtual campus ecological pond for educational applications. It incorporates real ecological situations of aquatic habitats into learning activities to improve the learning interest and motivation of students. They can use the touch screen and motion-sensing control to observe the features of aquatic plants and aquatic animals, and understand the relation between ecological balance and food chain through role playing and game missions. The virtual ecological pond can save the cost and manpower for building and maintaining a real ecological pond. It can also solve the problems of insufficient species and difficulty to observe under water. Students can see many kinds of aquatic plants and aquatic animals from different angles to discover their features, and play the roles of various aquatic animals to understand the relationship between producers and consumers.

Many studies proposed the concept of game-based learning and their results revealed that incorporating serious games into learning makes the learning process more interesting and challenging and thus increases learning motivation and effectiveness. Ellington et al. [13] discovered that playing games with learning contents allows learners to dedicate in the interesting learning process for a long time. Rosas et al. [14] found that teaching with video games is effective on increasing learning motivation, achievement, cognitive development, and concentration. Papastergiou [15] proposed that game-based learning possesses the features of multiple sensory cognition and problem-based learning. It helps learners to associate with previous cognition and experiences to obtain more advanced knowledge, and provides instant feedback for them to achieve interactive learning. Besides, game-based learning enables learners to better retain memory as compared to traditional teaching methods.

The virtual campus ecological pond developed in this study is in accordance with the design principle of game-based learning. The users must play different roles to complete the missions and solve the problems, and they can obtain useful knowledge and the sense of achievement after completing the missions. For example, the users may play as different aquatic animals when they log into the system to experience hunting and being hunted in the ecological pond. The role-playing game makes them understand the relationship between producers and consumers in a food chain. When an external or stronger species invades the ecological pond, the users can also choose to play the role of a pond manager to eliminate the invaders and restore normal operation of the ecosystem.

Education with entertainment has always been the ideal of many educationalists. The virtual campus ecological pond developed in this study has the functions of education and entertainment. It is designed to simulate a real ecological pond for students to observe the features of different aquatic organisms and their living environments by using the touch screen and motion-sensing control on mobile devices. It can enhance the learning interest and motivation of students by role-playing games and is therefore a useful tool for science education in elementary schools.

2. LEARNING CONTENTS

The virtual campus ecological pond developed in this study integrates the learning contents of aquatic organisms and habitats with the VR technology, situated learning and game-based learning to enhance students' learning interest and motivation. To achieve the learning objectives,

its learning contents have to be analyzed first and the system is designed according to the learning objectives.

Because situated learning emphasizes learning in realistic environments, the learning model adopted in this study is focused on the connection with real-life experiences to provide students with practical knowledge. The learning contents adopted in this study were based on the “Aquatic Organisms” unit, and they were analyzed according to the learning objectives before making the teaching plan. A virtual campus ecological pond was developed according to analytical results. Some missions and role-playing games were incorporated into the observation and learning process to improve students’ learning interest and motivation. The 3D modeling techniques for designing the virtual aquatic plants, aquatic animals and the ecological pond are shown in the following sections. Finally, the user interface design and the role-playing games are described.

In this study, the science and technology textbooks used in elementary schools were reviewed and it was found that the “Aquatic Organisms” unit appears mostly in grade 4. The science textbook published by Hanlin [16] was adopted and the outlines for its learning objectives and teaching activities were analyzed and listed in Table 1. This study incorporated concepts of food chain and ecological balance into role-playing games and missions, enabling users to understand the role of each aquatic animal in the ecosystem and how to maintain its diversity.

Table 1. Learning objectives and activities

Objectives	Activities
Aquatic Habitats	(1) Learning about different aquatic habitats in our daily lives (2) Learning about the characteristics of aquatic habitats
Aquatic Plants	(1) The aquatic plants can be divided into submergent, emergent, floating, and rooted-floating plants according to their growing methods. (2) The submergent plants have long stalks and their leaves are soft, long and thin. (3) The leaves of most floating plants are filled with air and their sizes are small.
Aquatic Animals	(1) Learning about aquatic fishes, insects, and amphibians (2) Learning about the insects living around the aquatic habitats
Motions of Aquatic Animals	(1) Learning about the motions of different aquatic animals made by using different parts of their bodies
Protecting Ecological Ponds	(1) Learning how to protect ecological ponds (2) Knowing the damage caused by alien species to the ecological pond (3) Knowing the effects of superior species to the ecological pond (4) Aquatic animals shouldn’t be abandoned in the ecological pond.

This study used 3ds Max [17] to develop the 3D models of the ecological pond and the aquatic plants/animals, which were exported into Unity3D [18] for the design of user interface. The authoring tool of Unity3D was used to convert the design into the installation file for execution on mobile devices (Android 4.0 OS) and it was published on Google Play for users to download. The procedure for developing the virtual aquatic plants includes: determining species, designing texture images, creating 3D models, reducing the sizes of texture images and duplicating aquatic plants. These steps are described in more details in the following section.

3. VIRTUAL AQUATIC PLANTS

Aquatic plants refer to plants living in the water and they differ from ordinary plants as they are more dependent on water for living. Although aquatic plants all live in water, their appearances and growths are different depending on the depth of water and its flow. Aquatic plants are categorized as floating and rooted plants according to the distribution of their roots in the soil. The latter can be further divided into submergent plants, emergent plants and rooted-floating plants. The features of aquatic plants are described in the following:

(1) Floating plants

This type of plants float entirely on the surface of water and their roots are suspended in the water without touching the soil. Their leaves are usually broad and wide in order to increase the contact area on the water surface for easy floating. Some of these plants are in the shape of a lotus to float on the water steadily. In this study, duckweed, *Azolla pinnata*, and water lettuce were selected as representatives of floating plants in the virtual ecological pond.

(2) Submergent plants

The roots of these plants are fixed to the pond bottom and their stalks and leaves are completely submerged in the water. Only the flowers and part of the stalk can emerge from water surface and some of the flowers are submerged in the water as well. Submergent plants are usually soft and able to adapt to the change of water depth by swinging in the water flow. This study chose eelgrass and waterweed as representatives of submergent plants.

(3) Emergent plants

For emergent plants, only a small part of their roots is submerged in the water and their stalks or leaves are usually above the water. Their leaves and stalks are strong in order to stand above the water and the flowers and fruits are similar to those growing on land. This study chose umbrella papyrus, cattail, bog bulrush, elephant ear, lotus, and whorled umbrella plants as representatives of emergent floating plants.

(4) Rooted-floating plants

The roots of these plants are anchored into the pond bottom with their leaves floating on water surface and flowers above the water surface. However, their flowers and seeds still mature and grow in the water. These plants usually have soft stalks or branches which are able to bend or extend according to the change of water level to keep their leaves floating on water surface. In this study, clover fern, water caltrop and yellow water lily were selected as representatives of rooted-floating plants.

3.1 Determining Species

There are more than 300 species of hydrophilic aquatic plants among many thousands of vascular plants distributed across Taiwan. Many of them are native and some of the rest are imported for appreciation in botanical gardens or aquariums. The authors visited the ecological pond at an elementary school in northern Taiwan before determining the species of aquatic plants for the virtual ecological pond. In addition, the aquatic plants introduced in the "Aquatic Organisms" unit were selected and those commonly seen in campus with distinctive features were also included in the virtual ecological pond (Figure 1).



Figure1. The aquatic plants in the virtual ecological pond

3.2 Designing Texture Images

The appearance and texture images are essential elements for designing the 3D models of aquatic plants because they are important factors affecting their sense of reality. Hence, the surfaces of the leaves selected as texture images must be clearly visible without being covered by other objects to facilitate the removal of background and creation of mask layer using image processing software (Figure2).



Figure2. Original image, background removed and mask layer

3.3 Creating 3D Models

This study used the solid modeling and cross-sectioning methods for creating the 3D models of aquatic plants. In the following, the water hyacinth and *Egeria densa* (Figure3) are used as examples for introduction. The water caltrop has unique appearance, so the solid modeling method is employed. However, the number of polygons in the 3D model must be reduced to prevent using too much memory space. The design criterion is to ensure that each aquatic plant model is formed by less than 300 polygons to reduce the memory space and computation time. As for *Egeria densa*, the leaves are luxuriant and the design requires excessive polygons when using the solid modeling method. Thus, this method can only be used for the stems and the cross-sectioning method is used for the leaves to reduce the number of polygons.

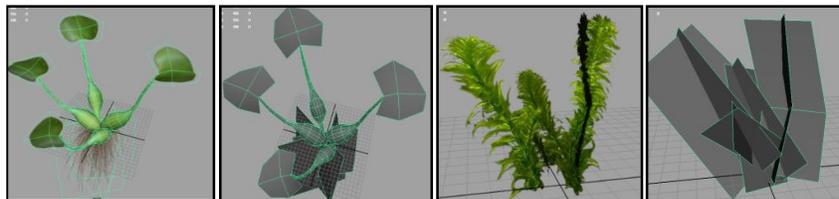


Figure3. Solid modeling (left) and cross-sectioning (right)

3.4 Reducing Texture Images

For virtual aquatic plants, the sense of reality is determined by the number of polygons in modeling and the resolution of texture images, and a higher resolution can often achieve a better visual effect. If each texture image is 35KB in size, there will be about 1.47MB of memory space required by 14 plants when each plant needs 3 images. However, more memory usage will cause excessive workload to the system during its execution. In order to save some memory space, the texture images of several aquatic plants can be merged into a single image and only 5 pairs of texture images and mask layers are required (with the size of each image or mask layer being 67KB) such that about 800KB of memory space is saved. The same method can also be used for the design of aquatic animal models.

3.5 Duplicating Aquatic Plants

To reduce the usage of memory space by resource sharing, only a model is created for each aquatic plant. The model and its texture images are designed using 3ds Max and PhotoImpact first and then exported to Unity3D for setting its properties and interaction. During execution, the aquatic plant is duplicated to produce the required copies and its properties can still be adjusted by sharing the same model and texture images. For instance, the size, position and moving direction can be adjusted to make the copies look different from the original one while the memory space can be saved to improve the system performance.

4. VIRTUAL AQUATIC ANIMALS

In aquatic habitats, the growth of aquatic plants will attract aquatic animals, especially herbivores, which can attract other predators and therefore increase the complexity of ecosystem and its food chain. Animals living in aquatic habitats include: fish, aquatic insects, reptiles, amphibians, and crustaceans. The aquatic animals in the virtual campus ecological pond are described in the following.

Insects are the most common animals in the world and they can be found in air, land, and water. Aquatic insects live in aquatic habitats and they comprise approximately 3% of all the insects found on Earth. These insects live in the bushes or ponds and they may leap on land, fly in the air, and glide on water surface and swim in the water. Some of these insects begin their lives in the water after hatching and migrate to land after maturing, such as nymphs (larvae of dragon flies). Some insects live in the water as larvae and migrate to land to become a cocoon, and they finally return to the water again after maturing, such as dytiscidae. There are also some insects dependent on water throughout their life cycles, such as waterscorpions.

In addition to various kinds of aquatic insects found in the water, many of them reside on the pond surface as well, such as water striders. The water strider has a longish body and long, hydrophobic legs to help them glide on water by surface tension. Dragonflies and damselflies are found commonly around ponds and they often reside on water surface or within the waterweeds. After mating, the females will fly above the water to lay eggs on aquatic plants or the water surface by tapping their tails continuously.

The amphibian is an important animal in aquatic habitats. They have two living forms as implied by the name: living in the water when they are young and migrating to the land after maturing. Even on land, they still have to live in moist environments to prevent dehydration of the skin. The most common amphibians are frogs and toads. Fish in the ponds feed mainly on plankton or larvae of aquatic insects. They are the natural enemy of mosquitoes and therefore form an

important part of the food chain. Many alien species have been introduced recently and they cause severe threat to the ecological environments in Taiwan. One such example is the giant Amazon snail which cause serious problems in the local ecosystems due to the abandonment by breeders. They have a strong reproductive ability, so their pink eggs can often be found along rich paddies. These snails feed on the young and tender parts of plants and thus have affected the harvesting of crops.

The process of developing virtual aquatic animals includes: determining species, creating 3D models, pasting texture images, adding the bone system, designing motions and duplicating aquatic animals, and these steps are described in more detail below.

4.1 Determining Species

Most ecological ponds are developed artificially, and some of the aquatic animals are bred manually. In this study, ten virtual aquatic animals are created, including: six aquatic insects (dragonflies, damselflies, nepidae, dytiscidae, dragonfly nymphs, and water striders), two amphibians (Ganaguentheri and tadpoles), and two fishes (Paradise fish and mosquito fish). Also, the giant Amazon snail is chosen as the foreign invader (Figure 4).



Figure4. The aquatic animals in the virtual ecological pond

4.2 Creating 3D Models

This study used 3ds Max to create the 3D models of aquatic animals according to hand-drawn sketches and the models obtained from the 3D digital scanner. The size and number of polygons must be decided before designing the 3D models to ensure the normal operation of the virtual ecological pond. Because there are many aquatic animals in the virtual ecological pond, this study adopted the low polygon design to prevent degrading system performance due to more memory usage and computation time when simulating the motions of aquatic animals.

4.3 Pasting Texture Images

The texture images of aquatic animals are obtained from photographs after removing the background and they are pasted to the surface of 3D models. Usually, the resolution of texture images will affect the sense of reality for the 3D models of aquatic animals. A higher resolution of texture images will make the models more realistic, but it may also incur a larger file size and thus increase the download and execution times. Let's take the 3D model of Ganaguentheri as an example. The texture images are pasted to the frog's 3D model as shown in Figure5 (left) using the UVW Map function of 3ds Max. The locations of the texture images can be further adjusted using the Unwrap UVW function to make the model look more realistic.

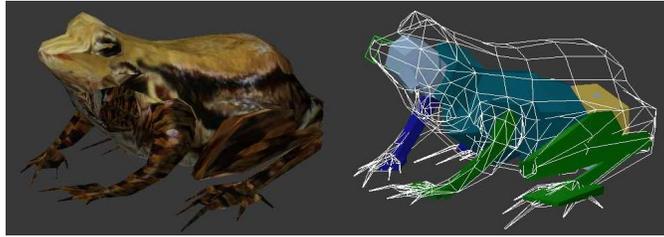


Figure5.Ganaguentheri model: pasting texture images (left),adding the bone system (right)

4.4 Adding the Bone System

The Xform in 3ds Max must be reset after the 3D model is completed to ensure that no deformity may occur when it is exported to Unity3D for motion design. Before that, the commands used for developing the 3D model have to be collapsed and the bone system has to be added to simulate the motions of aquatic animals. In Figure5 (right), the bone system is incorporated into the major parts of the frog's 3D model including its head, thorax, limbs and so on. The linkage between the bone system and the model must be examined carefully to prevent dragging unnecessary parts of the body to cause deformity during the motion.

4.5 Motion Design

In order to simulate the motions of the aquatic animals in the virtual ecological pond, their dynamic features have to be analyzed according to the recorded films. After that, a number of motions are selected for each animal to simulate their behavior. For example, the three set of motion (flying, tapping tail and resting) for dragonflies and damselflies are segmented into several frames as shown in Figure 6. To avoid discontinuity of different motions during conversion, the same posture is used in the initial and end points of the sequence. The motion is set to occur at the same place, and the actual displacement and rotational in the virtual scene are calculated by using the programs in Unity3D.

Flying motion	
Tapping tail	
Resting motion	

Figure 6. The motion design for dragonflies and damselflies

In the virtual ecological pond, the motions of dragonflies, damselflies, and frogs are more complicated. Three sets of motions are designed for dragonflies and damselflies, i.e., flying, resting and tapping the water. The dragonflies and damselflies are simulated to fly above the water, and a tapping motion will take place when they touch the water surface. In addition, they must stop and rest if the contact is with an aquatic plant. The probabilities of these motions are different and the contact with an object is set as the conversion point of different motions, which can be done by the programs in Unity3D. For example, the dragonfly flies for a time interval and a random motion conversion occurs. The length of time and fly direction are determined randomly by programs and the same process will repeat again after the time runs out.

4.6 Duplicating Aquatic Animals

In order to provide the virtual ecological pond with several aquatic animals without causing a large file size, multiple aquatic animals are duplicated by programs in Unity3D. The size, location and moving direction of the duplicated aquatic animals are controlled by the programs and their motion conversion is randomized to produce different paths and motions for the same kinds of aquatic animals, making the simulation more natural. The collision detection function in Unity3D is employed to specify the contact conditions with the virtual scene. For example, the floor property is set on certain crawling species such as the giant Amazon snails. After doing that, they can remain on the ground to prevent the situations of floating in the space, water or beneath the pond bottom from happening.

5. VIRTUAL SCENE DESIGN

To provide a suitable living environment for aquatic plants and aquatic animals, the natural aquatic habitat must be simulated during the construction of ecological ponds. In this study, the virtual campus ecological pond was developed based on the condensed natural habitats proposed by Sugiyama [19]. Its concept involves the naturalization of multiple organic resources using artificial methods. The main elements of a condensed natural habitat include: base conditions, plantation factors, porous materials, diversified environments and continuous spaces (Figure 7).



Figure7. The condensed natural habitat adopted in this study

(1) Base conditions

Base conditions refer to the landscape of the green area and the soil used to bear the organisms. The base conditions will affect the growth of organisms and the development of ecological system in the future.

(2) Plantation factors

Plants are the basic producers and their basic production value will determine the growth of living population in an ecological environment. Therefore, planting different types of aquatic plants (floating, submergent, rooted-floating, and emergent plants) in the ecological pond will facilitate the growth of aquatic insects and other aquatic animals.

(3) Porous materials

Most aquatic animals require appropriate habitats for living and reproduction. Consequently, porous materials such as gravel, hollow bricks and pebbles can be used to provide aquatic insects

with hiding spaces. Besides, dragonflies' larvae prefer living in shallow water, so groves or withered grass can be placed on the pond bottom to prevent them from preying on each other.

(4) Diversified environments

Diversified environments are helpful to maintaining biological resources and diversity. Frogs, fish and aquatic insects rely greatly on aquatic environments and thus it is necessary to create hydrated basins to facilitate their survival. Basins filled with straws can provide aquatic animals with suitable habitats for living and reproduction.

(5) Continuous spaces

The various protective zones of an ecological pond should consist of connecting passages within separated green lands to prevent restriction of different species and the isolation of ecological systems.

In this study, the virtual ecological pond was designed according to the five elements of the condensed natural habitat mentioned above to simulate the living environment of a natural aquatic habitat and to satisfy the requirement of learning objectives. The edge of the ecological pond in this study is sloped gradually to match the living habitats of various aquatic plants. Sand, pebbles and logs are placed on the pond bottom with irregular heights to provide a suitable living habitat for aquatic animals (Figure 8).

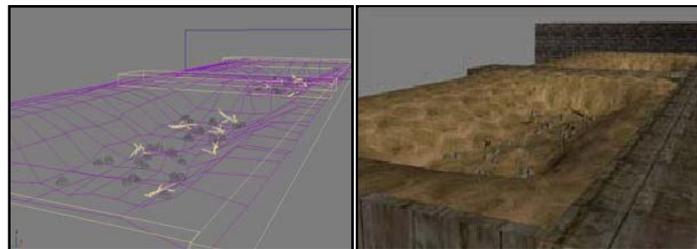


Figure8. Landscape of the virtual campus ecological pond

The main roles of the virtual campus ecological pond include: aquatic animals, aquatic plants, and the pond manager. This study developed 14 virtual aquatic plants, and 10 aquatic animals according to their characteristics and ecological environments to show a diversified and balanced aquatic ecosystem. The distribution of various aquatic plants was arranged according to the principles of condensed natural habitats. Emergent plants were grown along the pond, including: umbrella papyrus, cattail, bog bulrush, elephant ear, lotus, and whorled umbrella plants. Rooted-floating plants were grown in the water with their leaves floating on the water surface, including: clover fern, water caltrop and yellow water lily. Submergent plants were attached to the pond bottom and totally submerged in the water, including: eelgrass and waterweed. Rooted-floating plants were floating on water surface, including: duckweed, Azolla pinnata, and water lettuce (Figure 9).



Figure 9. The completed virtual ecological pond

The aquatic animals were distributed to various locations in the virtual ecological pond based on their characteristics, habitats and food sources. The aquatic animals living in the water include: Paradise fish, mosquito fish, tadpoles, giant Amazon snails, and various aquatic insects (dytiscidae, dragonfly nymphs, nepidae). Those living on water surface include: water striders, dragonflies, damselflies, and Ganaguentheri. This study used programs in Unity3D to control the amount of aquatic animals according to the food chain for the simulation of ecological balance. It can also allow students to understand the influences of superior species and foreign invaders on ecological balance. The parameters affecting the operation of ecological pond such as the water level and oxygen content are also simulated by programs in Unity3D to show their importance to aquatic ecological environments.

6. USER INTERFACE DESIGN

This study used the VR technology and sensor functions of mobile devices to develop a virtual campus ecological pond, providing a useful tool to solve the problems encountered in using (or without) a real ecological pond. To provide the users with an in-depth and convenient way of observation, the angle of first-person camera is adopted to simulate the human visual effects. The camera is mounted on a mobile 3D frame controlled by motion-sensing operation such that the users can submerge into and emerge from the water for easy observation (Figure 10).



Figure 10. Observation above (left) and under (right) the water of virtual ecological pond

The users can utilize the touch screen and motion-sensing control to observe aquatic plants and aquatic animals to better understand their appearances and characteristics and become aware of the ecosystem and its food chain. They can use touch-screen control to move the camera forward, backward, upward and downward to observe the ecological pond from different positions. To enable observation from different angles, this study used the electronic compass and 3-axis accelerometers on mobile devices to control the user's viewing angle and moving direction in the virtual ecological pond. As a result, the touch screen and motion-sensing operation provides the users with an interactive and immersive way of observation.

6.1 Moving Forward and Backward

The system uses the operation mode of two-point touch to control the moving forward and backward actions in the ecological pond. It will first determine if the operation is a two-point touch, and then apply the Pythagorean theory to calculate the distance between the two points. The camera will move forward (Figure 11, left) if the distance between the two points increases, and move backward if the distance decreases (Figure 11, right). The program for multi-touch control is shown in Figure 12.

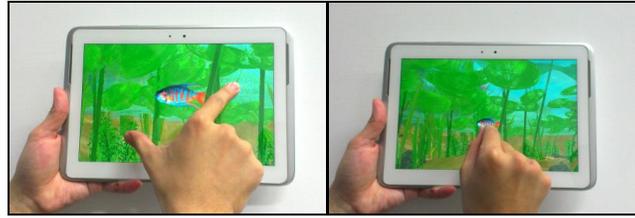


Figure 11. Moving forward (left) and backward (right) using the multi-touch control

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16  ---判斷多點觸碰，nTaps0==1 and nTaps1==1 為兩點觸碰
17  if (nTaps0==1 and nTaps1==1 and nTaps2==0 and nTaps3==0 and nTaps4==0)
18  then
19  ---計算觸碰兩點間距離
20  local s = math.pow(nX0-nX1,2)+math.pow(nY0-nY1,2)
21  if (this.old ( )==0)
22  then
23  this.old ( s )
24  else
25  local hcamera = application.getCurrentUserSceneTaggedObject ( "User_Camera" )
26  ---兩點距離越來越大，則攝影機往前，縮小則後退
27  if (s-this.old()>0)
28  then
29  object.setTranslation ( hcamera,0,0,-0.5,object.kLocalSpace )
30  else
31  object.setTranslation ( hcamera,0,0,0.5,object.kLocalSpace )
32  end
33  this.old ( s )
34  end
35  end
36

```

Figure 12. The program for multi-touch control

6.2 Moving Up, Down, Left and Right

The system uses the single-touch control to simulate the operation of moving up, down, left and right in the virtual ecological pond. It obtains coordinates of the final touched point (x2, y2) which are subtracted by the coordinates of the initial point (x1, y1). The larger value determines the moving direction and the subtracted values of x and y determine the moving distance, e.g., $x_2 - x_1 > 0$ implies that the user is moving from right to left and $y_2 - y_1 > 0$ implies that the user is moving from top to bottom using the single-point touch control. The operation of moving the camera downwards is used to simulate the user's diving into the water. Figure13 shows that the user is moving to the left (left) and to right (right) under the water; Figure14 shows the user is flowing above the water (left) and diving into the water (right) using single-touch control. The program for single-touch control is shown in Figure 15.

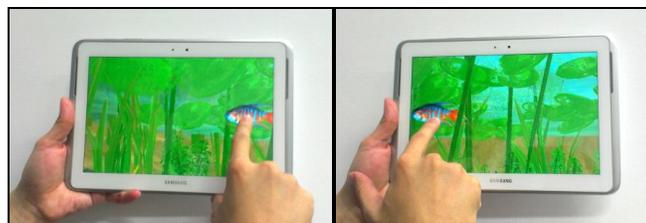


Figure 13. Moving to the left and to the right under the water

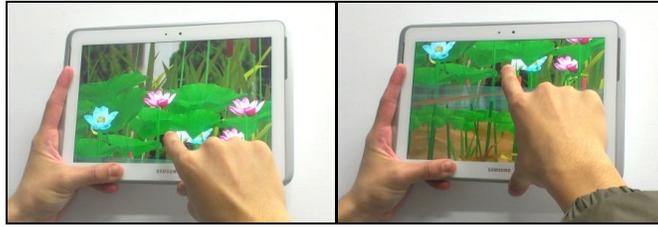


Figure 14. Floating above and diving into the water

```

37  ---nTaps0==1 and nTaps1==0 為單點觸碰
38  if(nTaps0==1 and nTaps1==0 and nTaps2==0 and nTaps3==0 and nTaps4==0)
39  then
40      if (this.old_x ( ) == 0 and this.old_y ( ) == 0)
41      then
42          this.old_x ( nX0 )
43          this.old_y ( nY0 )
44      else
45          local hcamera = application.getCurrentUserSceneTaggedObject ( "User_Camera" )
46          local x = nX0-this.old_x ( )
47          local y = nY0-this.old_y ( )
48          ----判斷手指滑動方向,如果是上下變化量較大的化,則做上下平移的動作,否則為左右平移
49          if ( math.abs ( x ) > math.abs ( y ) )
50          then
51              ---判斷手指方向,來決定移動方向
52              if ( x > 0 ) ---左右
53              then
54                  object.setTranslation ( hcamera,-0.5,0,0,object.kLocalSpace )
55              else
56                  object.setTranslation ( hcamera,0.5,0,0,object.kLocalSpace )
57              end
58          else
59              if ( y > 0 ) ---上下
60              then
61                  object.setTranslation ( hcamera,0,-0.5,0,object.kLocalSpace )
62              else
63                  object.setTranslation ( hcamera,0,0.5,0,object.kLocalSpace )
64              end
65          end
66          this.old_x ( nX0 )
67          this.old_y ( nY0 )
68      end
69  end

```

Figure 15. The program for single-touch control

6.3 Changing Direction

To enable observation from different angles, the system uses the electronic compass and 3-axis accelerometers in mobile devices to control the camera's angle when the users rotate their bodies or lift/bow their heads in the virtual ecological pond. The system obtains the azimuth angle from the electric compass of the mobile device and rotates the camera along the y axis in the world coordinate system accordingly as if the user rotates in the ecological pond. Figure 16 (left) shows the initial view of the ecological pond, and Figure 16 (right) displays another corner in the ecological pond after the user rotates 90 degrees clockwise. The program for obtaining the current direction is shown in Figure 17.



Figure 16. The virtual scene before and after rotating

```

14
15 local hcamera = application.getCurrentUserSceneTaggedObject ( "User Camera" )
16 local nHeading = math.trunc(system.getLastKnownHeading ( ),1) ---取得系統羅盤數值，並且四捨五入至小數點第1位
17 object.rotateToYPR ( hcamera,nHeading,0,0,object.kGlobalSpace,0.5 ) ---以世界座標轉動至nHeading角度
18

```

Figure 17. The program for obtaining the rotation angle

Unity3D has built-in API functions to obtain the values of 3-axis accelerometers, so the system can use trigonometric functions and acceleration values to calculate the elevation of the mobile device. When the user changes the elevation of the mobile device, the camera is rotated by the same angle to simulate the action of lifting (Figure 18) or bowing (Figure 19) head in the virtual ecological pond for the user to observe the aquatic plants and animals easily. The motion-sensing operation provides an immersive and interactive way of observation in the virtual ecological pond. The program for obtaining the elevation angle is shown in Figure 20.

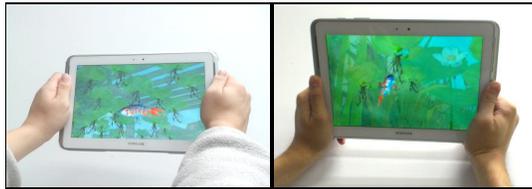


Figure 18. Lifting head by holding mobile device upward



Figure 19. Bowing head by holding mobile device downward

```

15 local hcamera = application.getCurrentUserSceneTaggedObject ( "User Camera" )
16 local ata = math.atan2 ( nAxisX,nAxisZ ) ---透過atan2計算加速度感測器所得X、Z方向後的仰角
17 this.ata_h ( math.trunc(ata,1) ) ---取到小數點後一位
18 object.rotateToYPR ( hcamera,0,this.ata_h(),object.kGlobalSpace,0.5 ) ---以世界座標轉動至this.ata_h()角度
19

```

Figure 20. The program for obtaining the elevation angle

7. MISSIONS AND GAMES

In this study, many observational missions were designed to increase students' learning interest and motivation about aquatic plants and animals in the virtual ecological pond. They can also experience the process of hunting and being hunted during the role-playing games to better understand the relationship between producers and consumers in the virtual ecological pond. After gaining enough experience value through the observational missions, they can play as the pond manager whose duty is to eliminate the foreign invaders to restore the ecological diversity in the virtual ecological pond. The missions and games allow users to accept challenges, identify problems and solve problems. By doing these, they can obtain the sense of achievement and practical knowledge for applications in the future.

7.1 Observational Missions

In this study, the observational missions were designed according to learning objectives of the "Aquatic Organisms" unit. The users have to observe aquatic plants and aquatic animals in the

virtualecological pond by using touch-screen and motion-sensing control to obtain knowledge about their features and the base conditions essential to their survival. Taking the mission “Finding out the rooted-floating plants in the ecological pond” as an example, the system will display a “correct” message when the user clicks on the clover fern, water caltrop or yellow water lily and then show a brief introduction to the selected plant. The user can earn some virtual money and experience value upon completing the mission and understand that the roots of these plants are fixed to the pond bottom and their leaves float on the water surface and the flowers are usually above the water.

Upon completing all missions of observing aquatic plants, the user will know that the aquatic plants can be divided into: submergent, emergent, floating, and rooted-floating plants according to how they look and grow. In addition, the user can identify the appearances and structures of different aquatic plants to associate with the ecological environments. After completing the missions of observing aquatic animals, the users can learn to identify the appearances, structures, and motions of different aquatic animals and understand that a fish is slender at the head and tail, and its body is flat to decrease water resistance for swimming faster. In addition, a fish depends on bending movement of its body in S shape to propel the water to create a forward thrust. The users will receive the expert medals of “Aquatic Plants” and “Aquatic Animals” upon completing the observational missions, showing they have gained a basic understanding about aquatic plants/animals, ecological environment in the ecological pond and the essential elements for the survival of aquatic organisms. Then, the users can play the roles of aquatic animals and the pond manager.

7.2 Playing as Aquatic Animals

In this study, the food chain diagram (Figure 21) in the virtual ecological pond was created by consulting biologists and it was used to define the game rules and control the amount of aquatic species by the programs in Unity3D to provide users with better understanding about the relationship between producers and consumers at different levels. The user can select the roles of different aquatic animals when he or she logs into the system to experience the process of hunting and being hunted. For example, the user may play as a water strider which can only glide on water surface to eat mosquito larvae, small bugs and mosquito fish while it has to be cautious about the attacks from paradise fish in the water. The paradise fish can only swim in the water and feed on aquatic insects and mosquito fish, but it must be careful about the attacks from egrets above the water.

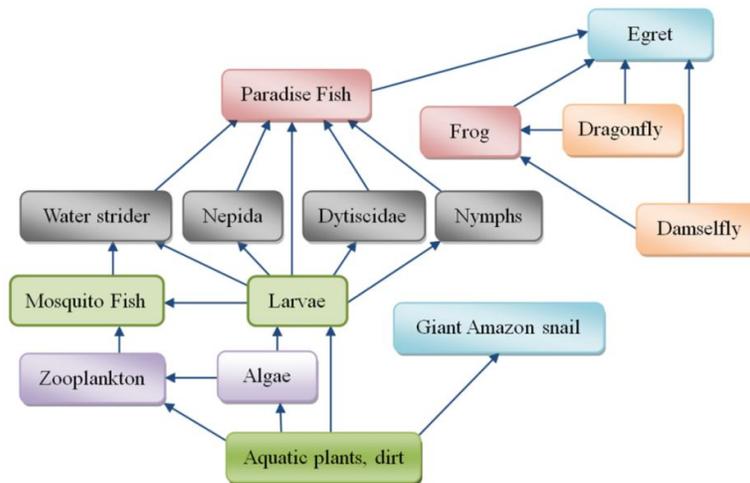


Figure 21. Food chain in the virtual ecological pond

The virtual ecological pond allows users to play the role of aquatic insects, amphibians, fishes or water snails to complete different missions. They will be awarded with a medal of each played animal after completing the mission and earn some virtual money and experience value. If they fail to complete the mission or the played role is eaten by other predators, they will lose some money and experience value and have to repeat the mission again. To enhance cooperation and competition between students, the user ID will appear on the played role for identification, and users can help or compete with each other during the missions to become familiar with the food chain in the virtual ecological pond. After completing the missions and satisfying the minimum requirement of virtual money and experience value, the user can also play the role of a pond manager to learn about the essential elements of aquatic habitats and to maintain the diversity and sustainability of the ecosystem.

7.3 Playing as the Pond Manager

The user cannot decide the manager's mission for which is triggered as a warning message according to the ecological pond's environmental conditions. The warning message is a reminder to maintain the normal operation of virtual ecological pond so that the pond manager must pay attention to the important parameters affecting its normal operation. For example, the pond manager must turn on the water pump to increase the water level when it is too low; the filter system has to be activated to improve the water condition when it becomes too dirty; the pond manager has to turn on the watermill when the oxygen content of the water is too low, and he or she must eliminate the invading alien species (such as giant Amazon snails and spirogyra) to protect the native species in the virtual ecological pond. The major duty of the pond manager is to maintain the water level/condition, oxygen content, and the ecological diversity in the ecological pond. The users will gain some experience value and advance to the next level after completing each mission, and they can earn the manager medal upon advancing to the highest level. The pond manager needs virtual tools such as: water pump, water filter, and watermill to perform the missions, and the users may use the virtual money earned in previous missions to purchase the required tools.

8. EMPIRICAL STUDY

An empirical study was conducted to evaluate the learning effectiveness of students after using the virtual ecological pond. This study adopted the quasi-experimental design by selecting two classes of 4th grade students from different elementary schools in northern Taiwan as samples, one class as the control group (26 students) and the other as the experimental group (25 students). This study used the "nonequivalent groups pretest and posttest" experimental design to analyze if different teaching tools would cause different learning achievements. In this quasi-experiment, the covariant term was student's ability before learning, the independent term was the teaching tool, the dependent term was students' ability after learning, and the control variants were the science teacher, teaching time (three weeks, two hours per week), and teaching materials. A questionnaire survey was conducted to analyze the attitudes of students after using the virtual ecological pond, and the results could also be used as a reference for improving the system design.

Before the teaching experiment, students in both groups took the pretest. After that, both groups studied the "Aquatic Organisms" unit for two weeks. For the experimental group, the teacher spent an hour to demonstrate how to use the virtual ecological pond on mobile devices. For the control group, the teacher spent an hour showing how to observe at the campus ecological pond. During the teaching experiment, the teacher used the same teaching materials to teach both groups. However, the experimental group could use tablet PCs to observe aquatic plants and aquatic animals in the virtual ecological pond and the control group could observe at the campus ecological pond. Two weeks later, the two groups took the posttest to see whether a significant

difference existed in their learning achievements. The test items included the aquatic habitats, aquatic plants and aquatic animals and protecting the ecological pond. To ensure the reliability and validity, the test items were designed based on the learning contents, course outlines and learning objectives of the learning unit, and then reviewed and revised by the science teacher.

A one-way ANCOVA was performed after the experiment to investigate if using the virtual ecological pond as the teaching tool could improve students' learning. The test of regression coefficient showed that the relation between the covariant term and the dependent term is not affected by the independent term. Therefore, it satisfied the hypothesis of equivalent regression coefficients between the two groups and was qualified for the covariant analysis. To analyze students' learning achievements on the "Aquatic Organisms" unit, this study used a dependent sample t-test to evaluate each group's pretest and posttest scores to see if a significant difference existed. According to the statistical results in Table 2, both the control group and experimental group improved significantly in the post test ($P < 0.05$). A one-way ANCOVA was conducted to see if a significant difference exists between their learning achievements.

Table 2. Statistical results for both groups

Group	Pretest	Posttest	T	P
Control	46.5	67.2	-21.2	<0.05
Experimental	44.4	75.8	-31.0	<0.05

The one-way ANCOVA used the pretest score as covariate, the teaching tool as independent term, and the posttest score as dependent variable, to perform statistical analysis. The results showed that the pretest score had a significant impact on the posttest score. After removing the influence of the covariate, the teaching tool had a significant impact on the posttest score ($P < 0.05$), showing the learning effectiveness of the experimental group was significantly higher than that of the control group. As a result, using the virtual ecological pond could improve students' learning more effectively than using the real ecological pond.

9. CONCLUSIONS

This study combined the VR technology with game-based learning and situated learning to develop a virtual campus ecological pond as a teaching tool for the "Aquatic Organisms" unit. The system incorporates real ecological situations into learning activities to enhance the learning interest and motivation of students. They can use the touch screen and motion-sensing operation to observe aquatic plants and aquatic animals and become familiar with the food chain through the role-playing games. The experimental results showed that the virtual ecological pond was more effective in teaching than the real ecological pond. The users can play different roles of aquatic animals and pond managers to better understand the relationship between producers and consumers and enhance their knowledge about biological diversity and ecological balance. In addition, it can solve the problems of insufficient species/amount and difficulty to observe underwater. The virtual ecological pond has the educational and recreational functions, so it is a useful tool for science education in elementary schools.

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