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Outdoor Natural Science Learning with an RFID-Supported Immersive Ubiquitous Learning Environment

Tsung-Yu Liu[1], Tan-Hsu Tan[2*] and Yu-Ling Chu[2]

[1]Department of Multimedia and Game Science, Lunghwa University of Science and Technology, Taoyuan County, Taiwan // Tel: +886-0922488664 // Fax: +886-2-32344001 // joye.liu@msa.hinet.net

[2]Department of Electrical Engineering, National Taipei University of Technology, Taipei, Taiwan // Tel: +886-2-27712171 // Fax: +886-2-27317187 // thtan@ntut.edu.tw // chu_yuling@tp.edu.tw

*Corresponding author

ABSTRACT

Despite their successful use in many conscientious studies involving outdoor learning applications, mobile learning systems still have certain limitations. For instance, because students cannot obtain real-time, context-aware content in outdoor locations such as historical sites, endangered animal habitats, and geological landscapes, they are unable to search, collect, share, and edit information by using information technology. To address such concerns, this work proposes an environment of ubiquitous learning with educational resources (EULER) based on radio frequency identification (RFID), augmented reality (AR), the Internet, ubiquitous computing, embedded systems, and database technologies. EULER helps teachers deliver lessons on site and cultivate student competency in adopting information technology to improve learning. To evaluate its effectiveness, we used the proposed EULER for natural science learning at the Guandu Nature Park in Taiwan. The participants were elementary school teachers and students. The analytical results revealed that the proposed EULER improves student learning. Moreover, the largely positive feedback from a post-study survey confirms the effectiveness of EULER in supporting outdoor learning and its ability to attract the interest of students.

Keywords

Augmented reality, Collaborative learning, EULER, Outdoor learning, Radio frequency identification (RFID), Ubiquitous learning

Introduction

To enhance the presentation of content in science courses, teachers often use classroom media such as science films or student activities such as experiments. Outdoor teaching is also a recognized method for enhancing learning and is widely used by elementary school teachers in Taiwan. However, the problems encountered in outdoor teaching include a lack of teacher expertise and appropriate teaching schemes. Students often make only quick and casual observations of outdoor conditions and materials, which may not yield sufficient or valuable knowledge. These factors and problems explain the growing interest in information technology applications in this area (Bellotti, Berta, Gloria, & Margarone, 2002; Chen, Kao, & Sheu, 2003; Yatani, Sugimoto, & Kusunoki, 2004).

Digital data and media accessed by mobile electronic devices offer new possibilities in learning. The mobility, flexibility, and instant access provided by modern mobile electronic devices enable students to engage in highly interactive activities at any place or time. Advanced wireless communication technologies enable a new learning model, mobile learning (m-learning). Mobile learning offers a new way to infuse learning into daily life. The advantages of m-learning over e-learning are flexibility, low cost, minimal equipment requirements, and ease of use (Jones, & Jo, 2004). Therefore, many investigations both inside and outside classrooms have assessed the use of mobile devices for enhancing education (Chen, Kao, & Sheu, 2003; Ogata & Yano, 2004; Chen, Kao, & Sheu, 2005).

Moreover, the rapid development of modern computer science and sensor technology has enabled many new ubiquitous computing applications. Ubiquitous computing refers to use of computer systems in everyday environments that enable user interaction at any time (Weiser, 1991; Weiser, 1998; Weiser, Gold, & Brown, 1999). A ubiquitous system provides users with timely information and relevant services by automatically sensing their various context data and by intelligently generating appropriate results (Kwon, Yoo, & Suh, 2005). In ubiquitous learning (u-learning), the ubiquitous computing occurs all around students, regardless of whether they are aware of it or not. Ubiquitous learning provides context-aware information and self-learning opportunities for learners. Thus, it not only enables students to achieve learning goals anytime and anywhere, it also cultivates their ability to explore new knowledge and solve problems. Ubiquitous learning has the following primary characteristics:

(1) Permanency. Learning processes are recorded and stored daily. A learning portfolio not only records the learning processes and achievements, it also records the learning behaviors and environment through a sensor and wireless network.
(2) Accessibility. Learners can immediately access information from any location.
(3) Immediacy. Learners can immediately access useful information at any time.
(4) Interactivity. Learners can interact or communicate with experts, teachers, peers, or the environment. Learning activities can be integrated into the real-world environment and can provide sophisticated, real-time, interactive services.
(5) Situation. The learning environment understands the situation of learners by detecting their status via the sensor network.
(6) Calmness. The learning devices are quiet, invisible agents that recede into the background of the learning environment.
(7) Adaptability. Learners can obtain the right information at the right place in the right way. The system actively adapts the subject content for various devices.
(8) Seamlessness. Learners can continue learning processes started elsewhere. The learning environment avoids interruptions in the learning process by adapting ongoing learning to accommodate changes in the learning environment (Chen, Kao, & Sheu, 2003; Ogata, Akamatsu, & Yano, 2005; Li, Zheng, Ogata, & Yano, 2005).

Additionally, we argue that “immersion” is a ninth characteristic of ubiquitous learning. In this context, immersion is defined as the state in which learners experience the same feelings and emotions as in a real world when interacting with virtual objects and environment. Hence, the characteristics of u-learning are permanency, accessibility, immediacy, interactivity, situation, calmness, adaptability, seamlessness, and immersion.

Context-aware systems featuring contextual data retrieval, engaging learning experiences, and improved learning effects have been applied in various learning activities (Cooper, 1993). The term “context-aware” was first defined by Schilit, Adams, and Want (1994), who regarded context in terms of location, identities of nearby people and objects, and the changes to those objects. Dey (2001) defined context as contextual information about an entity, which may be a person, a place, or a physical object. This information is considered relevant to the interaction between a user and an application. Although context-aware ubiquitous learning provides a more flexible, adaptive, and interactive learning experience than mobile learning (Li, Zheng, Ogata, & Yano, 2005), integrating immersion, calmness, seamlessness, and situation into a ubiquitous learning environment is extremely challenging. However, sensors and virtual reality technology are advancing rapidly. Sensor technologies, including IrDA, global positioning system (GPS), Bluetooth, RFID, Zigbee, and wireless local network (WLAN), can provide situated services. However, radio frequency identification (RFID) technology is particularly appropriate because it is inexpensive, highly accurate, very practical, easy to maintain, supports indoor/outdoor learning, and enables situated, calm, and seamless services (Hightower, & Borriello, 2001; Roussos, 2002). An RFID system identifies objects by transmitting internal codes from an RFID chip to a reader. The three main parts of the system are the reader, antenna, and tag. The reader device sends a signal through an antenna to a tag. This signal provides a small amount of power to activate the tag, which then transmits its internal code to the reader (Finkenzeller, 2003).

Conversely, integrating virtual reality (VR) into a ubiquitous learning environment increases immersion and provides a rich learning experience. Virtual reality can be classified as virtual reality, augmented virtuality, augmented reality, and real (Milgram, Takemura, Utsumi, & Kishino, 1994). In virtual reality, the surrounding environments are completely digitalized. In augmented virtuality (AV), real objects are embedded into virtual ones. In augmented reality (AR), digital objects are embedded into the actual environment (Hughes, Stapleton, Hughes, & Smith, 2005). According to Whiteside (2002), an immersive learning environment is effective if it engages the learner holistically — cognitively, emotionally, and even physically — using a combination of design techniques.

Various handheld AR-based learning games have been devised to explore the effectiveness of these technologies for learning. For instance, Wagner and Barakonyi (2003) proposed a handheld AR educational application in which a virtual character teaches users about art history. This study investigates how augmented reality helps create an effective and engaging educational application.

Although the ubiquitous learning systems described above have been successful in outdoor mobile learning, they still have unresolved problems. Specifically, teachers conducting outdoor teaching are unable to present complete information about objects and concepts such as historical relics, habitats of endangered wildlife, and geology landscapes. The following educational issues arise:

- how to achieve museum-like learning experiences in outdoor learning
- how to integrate real learning objects (exhibits) and teaching resources to deliver rich learning experiences to students and thus activate learning motivation and improve learning effects
- how to enable students to search, collect, share, and edit information, so that the goals of independent and collaborative learning can be achieved in outdoor learning
- how to cultivate students' ability to obtain and share knowledge, solve problems, and creatively collaborate in learning activities?

To address the above issues, this study proposes the environment of ubiquitous learning with educational resources (EULER), which employs RFID, Internet, wireless technology, augmented reality, embedded systems, and database technologies to enhance learning by using mobile learning, immersive learning, and ubiquitous learning with up-to-date technologies. The objective is to provide immersive ubiquitous learning environments for outdoor teaching. Additionally, this study develops interesting learning courses and explores how the proposed EULER affects the learning effectiveness of students. EULER has the following characteristics:

- Accessibility. Learners can use handheld devices to easily access learning resources via the Internet or a wireless local area network (LAN).
- Individuality. Learners can construct knowledge by organizing the learning content and by preparing a learning schedule.
- Immediacy. By using handhelds, learners can immediately access learning resources via the Internet or wireless LAN.
- Interactivity. Learners can interact with peers and instructors and can operate learning objects.
- Social interactivity. Learners can collaboratively complete a common task, discuss a common issue, and share their experiences with each other.
- Connectivity. Learners can exchange information and share files with each other.
- Situation. Learners can gain authentic knowledge of the natural environment.
- Context awareness. Learners can engage in context-aware learning activities in an actual outdoor environment.
- Seamlessness. Ubiquitous computing technology enables a continuous learning process even when the learners change locations.
- Permanency. The learning processes can be recorded in a learning management system and stored permanently.
- Immersion. By interacting with a virtual environment, learners can experience feelings and emotions that are similar to those experienced in the real world.
- Data collection. The system has sufficient multimedia capturing tools to help learners collect images, videos, and audio.
- Museum-like environment. An outdoor ubiquitous learning environment simulates learning in an indoor museum.

The learning effect of computer-based learning environments continues to be an important research topic. Webster and Hackley (1997) argued that quality, reliability, and ease of use of information technologies influence their effectiveness for learning. Webster and Hackley (1997) concluded that the most effective learning methods should include rich media, student-instructor interaction, and instructors who project positive attitudes. Piccoli, Ahmad, and Ives (2001) found that students with experience using technology and who have positive attitudes about technology tend to perform well in virtual learning environments. Leidner and Jarvenpaa (1995) stated that technologies promoting communication and interaction are effective for developing higher-order thinking skills and building conceptual knowledge when following a constructivist or collaborative learning model. Wells (1990) stated that technologies promoting participant communication are best suited for subject matter or course designs that emphasize discussion, brainstorming, problem-solving, collaboration, and reflection. Milheim and Martin (1991) defined three types of control that a learner may have, namely, learning pace control, learning sequence control and learning content control. Learning pace control refers to the speed at which course themes are presented. Learning sequence control refers to the order in which course themes are presented. Learning content control refers to the ability of learners to omit content themes with which they are already familiar. Giving learners some control over course components enhances the effectiveness and efficiency of learning environments according to a literature review by Merrill (1994). Piccoli, Ahmad, and Ives (2001, p. 404) defined interaction as "the degree of contact and educational exchange among learners and between learners and instructors." The interactive teaching style is positively related to learning outcomes (Webster & Hackley, 1997), control of the technology and technology attitudes (Leidner & Jarvenpaa, 1995), self-efficacy, and initial motivation. Piccoli, Ahmad, and Ives (2001) stated that students in highly interactive instruction may experience reduced isolation frustration, anxiety, and confusion, and gain positive learning effectiveness. Leidner and Jarvenpaa (1995) reported that the computers can provide learners with exercises similar to those in real-world situations. Given that previous studies asserted that the learning model affects the learning performance of students, this study explores how information technologies, interaction, learner control, and the learning model can improve outdoor natural science learning, based on student feedback by using EULER.

EULER

EULER consists of two subsystems, the mobile interactive learning environment (MOBILE) server for use by teachers and the mobile-tools (m-Tools) for students. Figure 1 shows the structure of EULER. Teachers can give lessons outdoors using a laptop computer with the MOBILE server installed. Teachers can install teaching materials in the mobile content database (MCDB) before class and establish assessments in the mobile assessment database (MADB). The MOBILE server addresses requests from students and responses to students during teaching. The learning activity management (LAM) unit constructs a virtual classroom that supports many learning activities, including bulletin boards, forums, voting, chatting, homework, assessment, and instruction. After completing outdoor teaching, teachers can conduct tests through a mobile assessment management (MAM) unit and analyze student performance. The mobile learning record database (MLRDB) stores student records, including assignment grades, reading times, number of discussions, instances of data collection, and instances of information sharing.

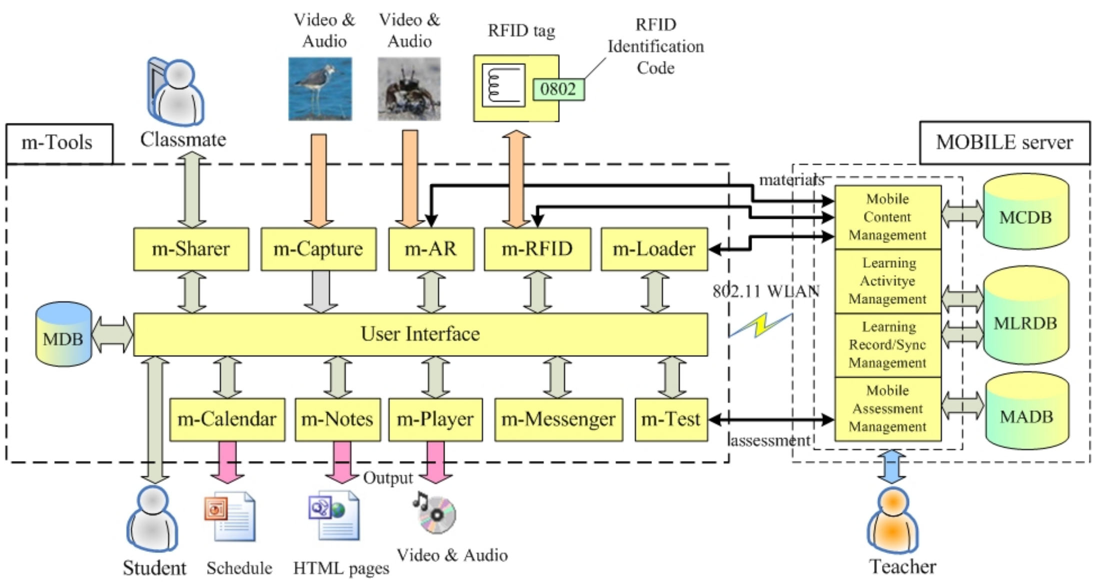


Figure 1. Structure of EULER and its two subsystems — the MOBILE server for teacher use and m-Tools for student use

The m-Tools system is installed on a PDA. It provides functions such as m-Loader, m-RFID, m-AR, m-Player, m-Capture, m-Sharer, m-Notes, m-Test, and m-Calendar. The user interface (UI) coordinates each tool and stores the learning records in the mobile database (MDB). For example, when a student using a PDA observes a zoo exhibition with an RFID tag installed, the RFID reader on the PDA identifies the internal code of the tag. The m-RFID then sends this code to the server, which in turn downloads context-aware content to the PDA. The student can then immediately browse the content by using the m-Player. Meanwhile, the m-Player can continuously update the MDB as the learner reads the material. Additionally, the student can use m-Messenger to receive teacher guidance, m-Capture to record videos of animals, and m-Loader to access additional materials from the EULER server. The student can later use m-Notes to compile collected information into articles and then use m-Sharer to send articles to the team leader via a wireless local area network (WLAN). The team leader can organize these articles, compile them into a team report, and submit the report to the teacher. The collaborative learning activity is then complete. Upon completion, students can employ m-Test to take online tests and evaluate their learning achievement. The m-Calendar can be used to organize personal learning schedules and to remind users about homework deadlines and test events. The m-AR can be used to enable students to see virtual creatures that would rarely appear in the wetland areas during this season.

Evaluation

A series of controlled experiments was performed using EULER for outdoor learning by fifth-grade students. After the experiments, a survey was conducted to evaluate EULER in improving student learning motivation and effectiveness.

Participants

The participants in this study were students in the Affiliated Experimental Elementary School of Taipei Municipal University of Education, which strongly emphasizes information technology education. Participants included four natural-science teachers and seventy-two students. All participating teachers had at least ten years of experience in computer-assisted instruction. Each student was assigned to either the experimental group or the control group. Each group had six teams of six students.

Equipment

The teacher employed a mobile server station, and students used PDAs to perform outdoor learning activities. The mobile server station was comprised of a laptop computer, a wireless access router, a rechargeable battery, and a wooden case (see Fig. 2). The laptop computer was an ASUS M3 with a Windows server 2003, SQL server 2005, and a wireless LAN (IEEE 802.11B/G). The PDA was a wireless-enabled ASUS 716A PDA with Pocket PC 2003, wireless LAN (IEEE 802.11B), Bluetooth, external camera, and external RFID reader. The PDA had a standard memory (SD) slot and a compact flash (CF) slot. For data storage, each PDA had an extra one-gigabyte SD. Additionally, RFID tags were installed in numerous information boards.

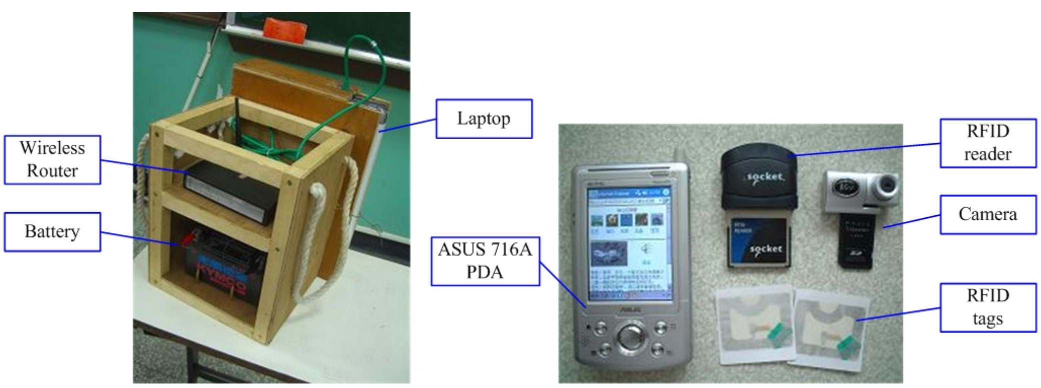


Figure 2. The mobile server station, comprising a laptop, wireless router, and rechargeable battery (right); The learning equipment, including PDA, RFID reader, camera, and RFID tags

Experimental method

Table 1 shows the quasi-experimental design of the study adopted for nonequivalent groups. This design required a pre-test and post-test for an experimental group and a control group. The experimental group adopted EULER for learning while the control group adopted traditional methods for learning. All participating teachers had at least ten years of experience in natural science instruction. Tests to evaluate student learning effectiveness were designed by participant teachers and were updated annually based on instructional requirements. Each test had 20 multiple-choice questions related to the course materials. Under these conditions, the tests had superior validity. Internal consistency of tests and questionnaire in the case study were measured by Cronbach's alpha coefficient. A Cronbach's alpha coefficient ranges from 0 to 1, and 0.7 is generally considered the minimum acceptable reliability coefficient (Nunnaly, 1978). Table 2 shows that all Cronbach's alpha coefficients in this experiment exceeded 0.7, which confirmed the reliability of tests used in the study. Pre-test questions examined prior student knowledge of wetland terminology, geology, and environment as well as related topics.

Post-test questions examined student learning during the course, including the importance of wetlands to human life, and the protection and restoration of wetland ecosystems and wetland creatures. An independent two-sample *t*-test was performed on the pre-test to determine whether the pre-conditions of two groups significantly differed. In the remaining activities, after the experiments were completed, ANCOVA was adopted to compare group differences in performance on each test with the previous test adopted as the covariance. The statistical data were examined to determine whether the learning performance of two groups significantly differed. Additionally, a statistical analysis was performed to evaluate the performance of the experimental group.

Table 1. Quasi-experimental design for nonequivalent groups

Learning phase	Control group	Experimental group
Preparation phase	Introduce the learning topics and goals	Introduce the learning topics and goals
Treasure-hunt game phase	Conduct a treasure hunt based on paper materials	Conduct a treasure hunt using EULER
Problem-solving project phase	Conduct problem-based learning based on a worksheet	Conduct problem-based learning using the m-Tools
Immersive learning phase	Conduct traditional outdoor learning using a text book	Conduct immersive learning using the m-AR
Evaluation phase	Conduct a post-test	Conduct a post-test

Table 2. Internal consistency of the tests

Test	Cronbach's alpha
Pre-test	0.84
Test1	0.76
Test2	0.80
Post-test	0.85

N = 72

To investigate the effect of EULER on student learning, a survey was administered to 36 students after they had completed the experiments. Responses to all questions were on a five-point Likert-scale from 1 for strongly agree to 5 for strongly disagree. Questions were divided into four groups: information technology (Group A), learner control (Group B), interaction (Group C), and learning model (Group D). Table 3 shows the Cronbach's alpha (α) coefficient of each group. These alpha coefficients exceeded 0.7, which confirmed the internal consistency and reliability of the survey.

Table 3. Internal consistency reliability of the survey

Group	Cronbach's alpha
A. information technology	0.76
B. learner control	0.79
C. interaction	0.84
D. learning model	0.80
Total	0.82

N = 36

Course design

Taiwan's wetlands include many creatures worthy of study. Therefore, a course on Taiwanese ecosystems was chosen for this study. The pedagogic strategy was problem-based learning (PBL) and the designated problem was

“How can the gradually disappearing wetland ecosystems in Taiwan be protected and restored?” The well-documented advantages of PBL over traditional teaching methods include improvements in self-directed learning, self-motivation, problem-solving skills, and knowledge-application skills (Jones, 1996; Stepien & Gallagher, 1993). The learning objectives of this course were as follows: 1) understanding wetland habitats and wildlife; 2) understanding the importance of wetlands; 3) understanding the relationship between wildlife and environment, and 4) understanding the concept and methods of environmental protection for wetland ecological systems. The main learning objectives of this course were to cultivate student problem solving and knowledge construction. The course learning procedures were as follows:

- Phase 1. Preparation phase (week 1)
  Students were divided into control and experimental groups. Teachers administered a pre-test to the two student groups before teaching. The pre-test had 20 multiple-choice questions. Teachers introduced the course topic and learning goals and explained how to use the learning tools.
- Phase 2. Treasure-hunt game phase (week 2)
  The teachers conducted a treasure hunt. The control group students employed a traditional method (using learning sheets) while the experimental group students used PDAs with RFID readers when visiting scenic spots with a treasure map. After answering four questions for each learning unit at the scenic area, the students proceeded to the next scenic area until all five scenic areas had been visited. Students were required to answer 20 multiple-choice questions in this phase for test #1.
- Phase 3. Problem-solving project phase (week 3)
  Students were assigned a problem-solving project based on a defined problem. The students were required to develop hypotheses, find evidence, synthesize knowledge, and explain phenomena. The control group employed the traditional learning method, while the experimental group used EULER to perform activities. Students were required to complete team project reports after school.
- Phase 4. Immersive learning phase (week 4)
  Students participated in an immersive learning activity to learn about wildlife rarely seen in wetlands. The control group students employed a traditional method (reading a book), while the experimental group students adopted the m-AR to see virtual creatures rarely seen in the wetland areas during this season. Teachers gave test #2, consisting of 20 multiple-choice questions, to both groups at the end of this phase.
- Phase 5. Evaluation phase (week 5)
  Teachers graded the project reports and highlighted those that were particularly good. Teachers conducted post-tests and surveys as well as in-depth interviews with teachers and students at the end of this phase.

Learning activities

The learning activities of the control group were based on traditional learning methods. The students who read the textbook and used notebooks to record information were instructed to compile the information on worksheets or in reports. Face-to-face interaction and oral communication between teachers and students were simultaneous. The experimental group, however, performed learning activities by applying EULER. The outdoor teaching was conducted in Guandu Nature Park, a famous wetland in the Taipei area (Wild Bird Society of Taipei, 2007). Student activities included a treasure hunt, a problem-solving project, and an immersive learning activity at Guandu Nature Park in phases 2, 3, and 4, respectively. Teachers used notebooks installed with the MOBILE server to conduct learning activities. Each student performed the learning activities on a mobile learning device with m-Tools installed.

In Phase 1, teachers introduced the course topic and learning goals and explained how to use the learning tools. In phase 2 of the outdoor teaching, the teachers prepared numerous information boards, each with an RFID tag attached. The teachers established the relationship between learning materials and the identification codes of RFID tags then placed the information boards near the corresponding wetland creatures. Each student carried a mobile device equipped with a video camera and an RFID reader when visiting scenic spots using the treasure map. Students approaching a scenic spot could use the learning device to identify the RFID tag attached to the information board. The detected identification code of the RFID tag was then transmitted via WLAN to the MOBILE server used by the teacher. The MOBILE server recognized the location of the students, and then transmitted the context-aware content to their learning devices. After completing a learning unit at one scenic spot, they answered four questions and then continued to the next scenic spot until all scenic spots had been visited. The team that completed the game first was given an award. The students thus accessed context-aware content related to actual wildlife, which enabled context-aware ubiquitous learning. Teachers gave test #1, consisting of 20 multiple-choice questions, to both groups at the end of this phase. Figure 3 illustrates the scenario at Guandu Nature Park using EULER. Figure 4 depicts examples of learning activities. Figure 5 shows the user interface of the MOBILE server. Figure 6 (a) presents a screenshot of the context-aware content.

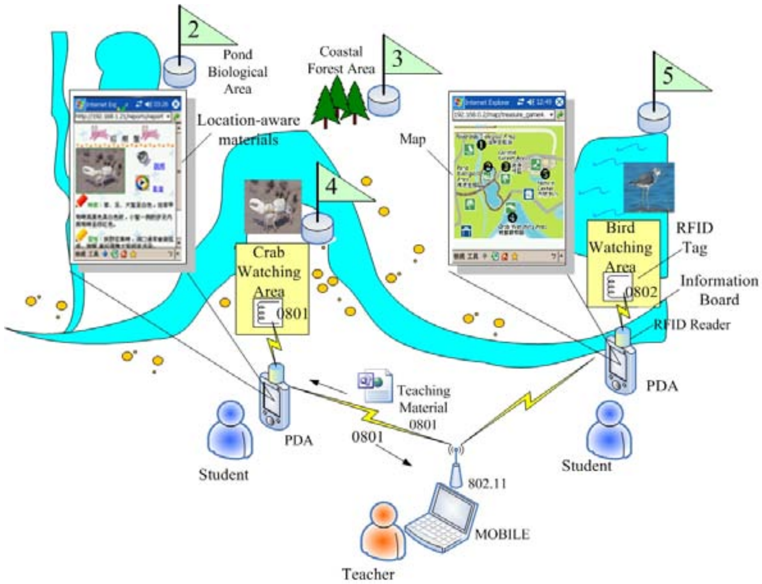


Figure 3. Guandu Nature Park scenario employing EULER

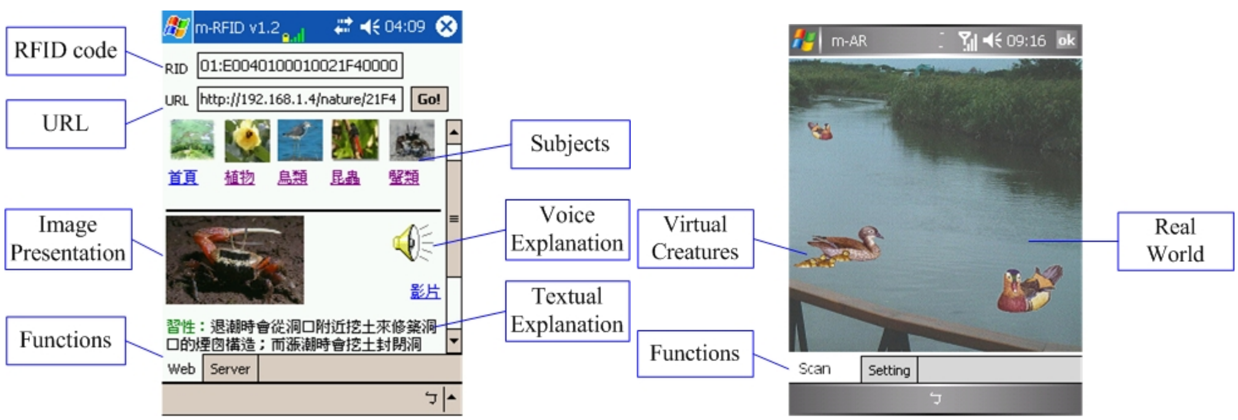
In phase 3, students were assigned a team project, "How to restore wetlands." Students were still unable to propose any feasible method after group discussions and therefore used the m-Messenger to request assistance from the teacher. Under the guidance of the teacher, team members applied m-Capture to capture images or videos of restoration projects currently being implemented in the wetlands and retrieve relevant information from the MOBILE server. This information was then compiled into articles. These articles were then sent to team leaders to create rich team project reports, which were submitted to teachers via WLAN. After all students had completed their outdoor learning activities and submitted their team project reports via m-Share, teachers posted the outstanding reports on the MOBILE server. These outcomes were evaluated by peer groups and teachers.

In phase 4, the immersive learning activity, experimental group students utilized the m-AR to observe virtual creatures that may not normally appear in the wetland areas during this season. For instance, students could see virtual mandarin ducks swimming in a stream. Figure 6 (b) shows a screenshot of virtual creatures. The control group students, however, only saw illustrations of the mandarin ducks in a book. Teachers gave test #2, consisting of 20 multiple-choice questions, to both groups at the end of this phase. In phase 5, the final week, a post-test was given to evaluate the learning performance of all students. A survey was administered to experimental group students after they had completed the course.


(a) (b)

Figure 4. Photographs of outdoor teaching activities: (a) students engaging in CSCL; (b) two students engaging in treasure hunt game

Figure 5. Screenshot of user interface of MOBILE server



(a) (b)

Figure 6. Screenshots of user interface of m-Tools: (a) m-RFID presents a context-aware content; (b) m-AR shows virtual mandarin ducks swimming in a stream

Results and discussion

An independent two-sample *t*-test was performed to analyze the pre-tests of both groups. The difference in average grades between the two groups in the pre-test ($t = -0.21$, $p > 0.05$) was insignificant, indicating that the prerequisites of the two groups of students were similar. To reduce the effect of student prerequisites on experiments, this study treated the pre-test as a control variable and omitted it. Table 4 shows the results (Sig. > 0.05) of the Levene's test for equality of variances, which confirmed the homogeneity of variances for the two groups. Additionally, the test results ($p > 0.05$) of between-subject effects, which indicate the assumed homogeneity of regression coefficients for the two groups, were gathered for the remaining tests. Accordingly, ANCOVA analysis was then performed. Table 5 presents the mean grades and standard deviation of evaluations for each test. Table 6 lists the ANCOVA and Cohen *d* results of the evaluations that were performed for each test. The effect size was used to measure significant differences between the evaluation results for each group. The values 0.2, 0.5, and 0.8 represent small, medium, and large effect sizes, respectively (Thalheimer & Cook, 2002).

In phase 2, the treasure hunt game, the ANCOVA results for test #1 ($F = 18.89$, $p < 0.05$, $d = 2.01$) indicate that the average grades of the experimental group exceeded those of the control group by at least 18 points. This statistically significant difference indicated that EULER was effective in improving learning. The interviews suggest that the difference may have been due to the ubiquitous learning activities provided by EULER, which provided a museum-like experience in outdoor teaching and further increased the student results.

Table 4. Levene's test for equality of variances and test for equality of regression slopes

Test	Test#1		Test#2		Post-test	
	F	Sig.	*F*	Sig.	*F*	Sig.
Levene's test for equality of variances	2.144	0.148	1.311	0.256	0.267	0.607
Test for equality of regression slopes	2.984	0.089	0.549	0.461	1.863	0.177

Table 5. Mean grades and *SD* of evaluations for each test

Test	Experimental group		Control group	
	Mean	*SD*	Mean	*SD*
Pre-test	41.4	10.13	42.6	9.97
Test 1	80.6	7.10	62.6	8.20
Test 2	85.2	9.24	74.6	11.58
Post-test	90.1	7.12	76.4	9.55

In phase 3, the problem-solving project phase, the average grade in the experimental group significantly exceeded (by 21 points) that of the control group ($t = 13.84$, $p < 0.05$) in the report evaluation, indicating that the proposed EULER and designed learning game improved the collaborative experience and abilities in exploring new knowledge, collecting information, sharing knowledge, constructing knowledge, and working collaboratively. Table 7 shows the independent two-sample *t*-test results for report evaluations.

In phase 4, the immersive learning activity, the ANCOVA results of test #2 ($F = 22.01$, $p < 0.05$, $d = 1.26$) indicate that the average grade of the experimental group significantly exceeded (by 11 points) that of the control group. The interviews suggest that this occurred because students could see virtual creatures that may not normally appear in wetland areas. This activity enabled the experimental group students to learn about wetland creatures more effectively than the control group students.

In phase 5, the evaluation phase, the ANCOVA result of post-test ($F = 27.07$, $p < 0.05$, $d = 1.80$) revealed that the average grade of the experimental group significantly exceeded (by 13 points) that of the control group in the post-test, showing that the proposed EULER improves learning achievement. The students indicated that EULER provides a ubiquitous learning model that effectively increased their interest and learning motivation.

Table 6. ANCOVA and effect size (*d*) results for two group tests

Test	Variance source	SS	MS	*F*	Effect size (*d*)
Test 1	Pre-test	921.88	921.88	18.89*	2.01
	error	3367.67	48.81		
Test 2	Test#1	1911.76	1911.76	22.01*	1.26
	error	5992.13	86.84		
Post-test	Test#2	1399.97	1399.97	27.07*	1.80
	error	3568.47	51.72		

*$p < 0.05$

Table 7. Independent two-sample *t*-test results for a project report

	t	Sig.	Experimental group		Control group	
			Mean	*SD*	Mean	*SD*
Project report	13.84	0.000*	91.4	6.04	70.2	6.91

*$p < 0.05$

Additionally, according to Table 8, the average post-test grade in the experimental group significantly exceeded that in the pre-test ($t = 40.42$, $p < 0.01$). This finding also demonstrates the effectiveness of EULER. Figure 7 plots the bar charts of the grades of the two groups. The average grade of the experimental group gradually increased and was higher than that of the control group, further indicating that the experimental group learned more effectively than the control group did. This finding also indicates the effectiveness of EULER.

Table 8. Dependent *t*-test results of pre-test and post-test for experimental group

	t	Sig.	*d.f.*	*M.D.*
Pre-test and post-test pair	40.42	0.000*	35	47.98

Test value = 41.40; $*p < 0.01$

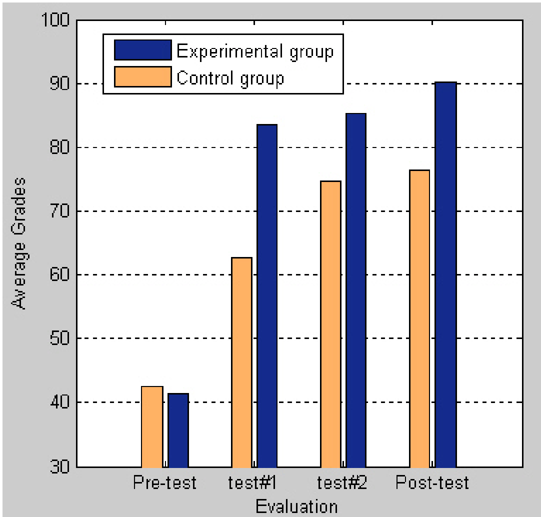


Figure 7. Bar chart of grades of two student groups, indicating that the experimental group learned more effectively than the control group did

A questionnaire was administered to the experimental group at the end of the learning activity. All 36 of the questionnaires distributed were valid, which was a 100 percent response rate. Table 9 lists the survey results, based on a 5-point Likert scale. The responses to item A1 indicated that most students thought that the m-Tools were easy to use (m = 3.83). One student stated, “I wanted to know whether crabs all move sideways. I found that one of the species called the soldier crab (*Mictyris brevidactylus*) is an exception. Using these ubiquitous learning tools, I could acquire new knowledge easily.” The responses to item A2 indicated that the system functions were convenient and sufficient for learning (m = 3.86). Most students considered PDAs to be novel devices, and opined that such learning experiences would not be possible without the handheld devices. Students also commented that the m-Tools had many functions with user-friendly interfaces that could assist them in completing the desired learning activities. One student stated, “Whenever I observed anything that I found interesting, I would use the video-capturing tool (m-Capture) to record the scenes and save them in the PDA memory card.” The responses to item A3 indicated that most students effectively used the m-Tools to collect, share, and analyze data, and further complete reports (m = 4.02). Many students indicated that using modern devices when learning outdoors is a diverting experience. They reasoned that m-Tools develop their abilities to use information technology to a degree not possible with traditional methods. One student stated, “I grew up in a big city. Except for occasionally visiting the zoo, I seldom had the chance to be exposed to wildlife. Most of my knowledge was acquired from textbooks. This outdoor learning activity allowed me to watch wild creatures but also deepened my understanding about their living environment and activities.” Result A3 also replied to the issue I4, reflecting the ability of EULER to cultivate student competence in acquiring and sharing knowledge, solving problems, and becoming creative in learning. The responses to item A4 indicated that most students thought that the screen size of the PDA was too small (m = 3.02). A larger screen would enable them to read the content easily. The responses to item A5 indicated that most students considered the audio quality of PDA inadequate (m = 3.28), such that they could not listen to materials clearly.

Item B1 indicates that students gained much more knowledge by using m-RFID than by using worksheets (m = 4.32). One student stated, “I could not only read webpage-based materials at any time, but could also watch biological creatures closely. I could verify what I had learned from textbooks with the knowledge I had gained in real life.” Item B2 indicates that students could collect more information by using m-Loader and m-Capture (m = 4.12).

One student stated, “I used m-Capture to capture some valuable photos and films. Many of my classmates were very jealous of me after they saw the photos and films.” Item B3 indicate that most students thought that the m-Sharer could help them share information with classmates (m = 4.02). Item B4 indicates that most students thought that m-Notes could help them complete common projects collaboratively (m = 4.06). One student stated, “Our group used m-Share to transfer the animal data that we gathered to the leader. After the leader prepared a report, he shared it with all the group members. Later, using the discussion tool, we discussed how to improve the report, where to add more text, and where to add new pictures. Through many discussions and revisions, we jointly completed the final report.” Results B1, B2, B3, and B4 also replied to the issue I3, reflecting the ability of EULER to enable students to search, collect, share, and edit information further to improve learning.

The responses to item C1 indicated that most students thought that using the m-Capture could increase interaction with natural environment (m = 4.22). One student stated, “I used the image-capturing tool (m-Capture) to take snapshots of animals that I observed. These picturesque records were authentic knowledge that I could not possibly learn from textbooks.” Responses to item C2 indicated that most students thought that using the m-Messager increased interaction with teachers (m = 4.13). Responses to item C3 indicated that most students thought that employing the m-Loader and m-Notes increased interaction with computers (m = 4.22). Many students commented that they were highly motivated to use modern devices such as PDAs. Responses to item C4 indicated that most students thought using the m-Sharer could raise interaction between classmates (m = 4.17). Results C1, C2, C3, and C4 also replied to the issue I2, illustrating the ability of EULER to motivate students in learning and improve learning.

Table 9. Summary of survey results from 36 students (5-point Likert scale)

Group	Item	Mean	SD
A. Information technology	A1. The user interface of the m-Tools is friendly.	3.83	0.78
	A2. The system functions of the m-Tools are convenient.	3.86	1.12
	A3. I am familiar with using m-Tools to collect, share, and analyze data, and to further compile them to a report.	4.02	0.71
	A4. The PDA display is sufficiently clear for reading learning content.	3.02	1.22
	A5. The PDA audio is sufficiently clear for listening to learning content.	3.28	0.98
B. Learner control	B1. Applying the m-RFID to outdoor learning helps me gain real knowledge.	4.32	0.64
	B2. Applying the m-Loader and m-Capture to outdoor learning helps our team in collect information.	4.12	0.77
	B3. Applying the m-Sharer to outdoor learning helps our team to share information.	4.02	0.86
	B4. Using m-Notes for outdoor learning helps our team complete assigned project collaboratively.	4.06	0.84
C. Interaction	C1. Using the m-Capture increases interaction with the natural environment.	4.22	0.74
	C2. Using the m-Messager increases interaction with teachers.	4.13	0.76
	C3. Using the m-Loader and m-Notes increases interaction with computers.	4.22	0.69
	C4. Using the m-Sharer increases interaction with classmates.	4.17	0.80
D. Learning model	D1. I enjoy the problem-solving learning activity because it enables me to understand the importance of wetland ecology protection.	4.12	0.77
	D2. I enjoy the treasure-hunt game because it makes outdoor learning interesting.	4.25	0.82
	D3. I enjoy the immersive learning activity because it enables me to watch virtual creatures in the actual natural environment and to learn about wetland wildlife.	4.33	0.72
	D4. I enjoy the RFID-based ubiquitous learning environment, which is similar to a natural museum.	4.22	0.74

d.f. = 35

Responses to item D1 indicated that most students enjoyed the problem-solving activities and understood the importance of wetland ecology protection (m = 4.12). One student replied that household wastewater, industrial wastewater, and agricultural chemicals all eventually flow into rivers. He thought wetlands became damaged because river water passes through them before running into the ocean. Responses to item D2 indicated that most students found that the multimedia learning materials and the on-site treasure hunt game added interest to the learning process (m = 4.25). Another student viewed the treasure-hunt game as new and interesting. She said, "I saw fiddler crabs waving fiddle claws and waterbirds looking for foods beside the pond. I could also reach out my hands to touch the Kandelia candel. In this activity, I could not only read webpage-based materials at any time, but also have a close watch on biological creatures. I could verify what I had learned from textbooks with the knowledge I gain in real life." Responses to item D3 indicate that most students observed many creatures that they had never seen before (m = 4.33). Many commented that they enjoyed watching virtual creatures on PDAs. One of them stated, "Through the m-AR function of the PDA, I could see a virtual Uca lacteal waving its fiddle claws on the swamp." Another student stated, "Through the m-AR, I could see virtual creatures that I did not to see in the wetland." Responses to item D4 show that most students regarded EULER as a natural science museum (m = 4.22). One student stated, "When I walked into a learning area, the RFID sensor device on my PDA could detect my location and tell the PDA to download relevant materials for me. I felt like I was visiting a museum." Result D4 also replied to the issue I1, illustrating the ability of students to attain museum-like learning experiences in this outdoor learning environment. Knowledge impressed students most favorably through actual, repetitive, and persistent operation of mobile devices. Therefore, student learning effect can be improved.

The interviews indicated the following reasons for the improvement:
1) EULER supports convenient and flexible functions and provides diverse educational applications for teachers.
2) EULER provides plentiful learning resources; students can learn flexibly and independently at any time and place.
3) EULER affords amusing learning activities, which increase learning motivation.
4) The m-tools help students to solve problems and stimulate their creativity through computer-supported collaborative learning (CSCL) activities.

Conclusions

This work presents an environment of ubiquitous learning with educational resources (EULER) scheme based on RFID sensor technology, the Internet, ubiquitous computing, embedded systems, and database technologies to help teachers develop diverse learning applications anytime and anywhere — even in locations without information presentation capacity. The proposed EULER consists of two subsystems: the EULER server installed on a notebook computer for use by teacher, and the mobile learning tools installed on a mobile device for application by a student. The EULER server helps teachers conduct outdoor learning activities involving various educational strategies, including collaborative learning, problem-based learning, and context-aware learning. Additionally, the mobile learning tools support student learning anytime and anywhere. A case study of natural science learning applying RFID technology was performed in classrooms and at the Guandu Nature Park with a learning topic entitled "Taiwan wetland ecosystems." The participants were four elementary school teachers and 72 fifth-grade students. Problem-based learning, computer-supported collaborative learning, and ubiquitous learning pedagogic strategies were adopted, and a series of formative learning activities were employed in five-week courses.

Test results obtained from learning activities revealed that the experimental group achieved significantly more learning improvement than the control group did. A survey was administered following all learning activities. The results indicated that most students found EULER easy to use, and most believed it could assist their learning. Further, the interview results reveal that, compared to traditional learning methods, the proposed EULER not only increases the motivation of students to learn and improves the effectiveness of learning, but it also improves student creativity and the ability to explore and absorb new knowledge and solve problems. The analysis of students' reports and interviews concludes that the destruction of wetlands caused by industrial pollution, solid waste, and engineering construction. We recommend that the government promote the concept of environmental protection and administer more artificial restoration projects.

This work demonstrates that RFID and AR technologies provide museum-like learning experiences in context-aware, immersive, and ubiquitous learning activities. Moreover, educators can benefit from the inclusion of educational objectives of acquisition of authentic knowledge, development of the sense of cooperation, training of problem-solving ability, improvement of learning motivation, stimulation of imagination, and creativity in future learning activities. Through these new learning activities, students' experiences in using technology to facilitate their learning can definitely affect their future learning. Hopefully, using EULER to present well-designed immersive ubiquitous learning can provide enjoyable and effective outdoor learning experiences.

In future work, efforts are underway to describe not only the educational affordances of EULER towards outdoor, natural science learning, but also the detailed process of interaction, collaboration, and learning by using EULER. Additionally, one new project is underway to employ new sensor networks, physical interaction, artificial intelligence, and ubiquitous AR technologies in the learning environment. Artificial intelligence and AR technologies enable students to virtually observe the behavior of creatures that would rarely appear in the wetlands and even creatures that no longer inhabit the earth. Students can interact with virtual creatures by using sensor networking and physical interaction technologies. This feature allows students to envisage the impact of human behavior on the environment and on other creatures and helps them to appreciate the need for environmental protection and understand how to live with nature.

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