Development and Evaluation of an RFID-based Ubiquitous Learning Environment for Outdoor Learning

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Many issues have been identified in outdoor teaching, especially in places that lack the capacity to effectively present information about such subjects as historical relics, rare animals, and geological landscapes. This study proposes an Environment of Ubiquitous Learning with Educational Resources (EULER) based on radio frequency identification (RFID), the Internet, ubiquitous computing, embedded systems and database technologies to resolve such issues. A case study of natural science learning was conducted in classrooms and at the Guandu Nature Park in Taiwan. Participants included elementary school teachers and students. The results of the evaluation in this study show that the proposed EULER significantly improves student motivation and learning. Furthermore, the results of a post-study survey reveal that most student feedback is positive, further indicating the effectiveness of the EULER.

Introduction

To help students on science courses teachers often teach outdoors, use scientific films in the classroom, and perform experiments. Among these methods, outdoor teaching is widely recognized as the most feasible method, which explains why elementary school teachers in Taiwan have frequently taught outdoors. However, most outdoor teaching approaches are ineffective because students lack expert guidance and appropriate outdoor learning tools. Often students can only observe outdoor conditions and materials quickly and casually and, therefore, do not gain sufficient or useful knowledge. Therefore, the application of information technology in outdoor teaching has become an attractive research topic (Bellotti, Berta, Gloria, & Margarone, 2002; Chen, Kao, & Sheu, 2003; Yatani, Sugimoto, & Kusunoki, 2004).

Advances in wireless communication technology have created a new learning model called mobile learning (m-learning). Mobile learning offers a new way to learn

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during daily life. The Center for Highly Interactive Computing in Education (Hi-CE) at the University of Michigan has been exploring how to use handheld computers in the K–12 environment since the autumn 2000 (Soloway et al., 2001). The Hi-CE project addresses the use of handheld computers as flexible tools that can be adapted to suit various teaching and learning styles. The advantages of m-learning over e-learning include flexibility, low cost, small devices size and ease of use (Jones & Jo, 2004). The role of mobile learning in improving outdoor teaching has been widely researched. A mobile scaffolding-aid-based bird watching learning (BWL) system provides cognitive tools to support outdoor nature and science education and to discover whether learning can benefit from the mobility and individualization afforded by mobile personal digital assistants (PDAs) (Chen et al., 2003). A mobile butterfly watching learning system, based on a wireless network and data mining technologies and using PDAs, has also been developed. This system offers a cognitive tool that supports independent learning and extended learning outside the classroom (Chen, Kao, and Sheu, 2005).

Other learning systems based on ubiquitous computing technology have recently been developed. These systems provide a more flexible, refined, and seamless learning experience than those cited above (Ogata & Yano, 2004; Li, Zheng, Ogata, & Yano, 2005). Ubiquitous computing refers to the computer system as part of the everyday environment in which users can interact with the system at any time. With the application of ubiquitous computing in learning, ubiquitous learning occurs all around the students regardless of whether they are aware of it or not (Weiser, 1991, 1998; Weiser, Gold, & Brown, 1999). The primary characteristics of ubiquitous learning are: (1) permanency—learning processes are recorded and stored daily; (2) accessibility—learners can access information immediately from any location; (3) immediacy—learners can immediately access useful information, regardless of time; (4) interactivity—learners can interact with experts, teachers, or peers through synchronous or asynchronous communication; (5) convenient situation of instructional activities—learning can be integrated into daily life (Chen et al., 2003; Ogata, Akamatsu, & Yano, 2005; Li et al., 2005). Several empirical studies have developed learning environments that apply ubiquitous computing technology. For instance, Jones and Jo (2004) presented the advantages of distributing learning materials to students via mobile devices using ubiquitous learning systems. Ogata and Yano (2004) developed a collaborative learning support system with a ubiquitous environment called CLUE, which allows individuals to share knowledge and to learn collaboratively.

Context-aware systems with features such as contextual data retrieval, engaging learning experiences, and improved learning effectiveness have been employed in various learning activities in recent years (Cooper, 1993). Dey (2001) defined context as contextual information that can be used to characterize the situation of an entity, which can be a person, a place, or a physical object that is considered relevant to the interaction between a user and an application. A number of studies have used this concept to build context-aware guide systems for museums. A hypermedia tour guide system has been constructed to understand how context-aware computing can
support a museum-like experience (Bellotti et al., 2002). Moreover, a context-aware guide system provides visitor-oriented services and enables visitors to share their experiences with others in a museum (Chou, Hsieh, Gandon, & Sadeh, 2005). Technologies such as IrDA, GPS, Bluetooth, and 802.11 can provide positioning services, but Radio Frequency Identification (RFID) is particularly convenient. RFID identifies an object by transmitting an internal code from an RFID chip to a reader. An RFID system consists of three main units, namely the reader, the antenna, and the tag. The reader is a device that emits 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). The Musex system, based on an RFID reader and a personal digital assistant (PDA), was developed to support collaborative learning by children in a museum (Yatani et al., 2004). The Tag Added learNinG Objects (TANGO) system detects objects around learners, and provides learners with object-related information using RFID technology (Ogata et al., 2005).

Although the systems described above have been successful in a wide range of learning applications, issues still remain to be solved. In particular, when teachers conduct outdoor teaching in locations such as historical sites, rare animal zones, and geological landscapes, in which complete information about objects and concepts cannot be given, the following issues arise.

1. How can museum-like learning experiences be achieved?
2. How can real learning objects (exhibits) and teaching resources be integrated to deliver rich learning experiences to students, to activate learning motivation, and to improve learning effectiveness?
3. How can students be enabled to search, collect, share, and edit information so that the goals of independent and collaborative learning can be achieved?
4. How can students discuss issues and share their achievements after class?
5. How can one cultivate the ability of students to acquire knowledge, share knowledge, solve problems, and be creative in collaborative learning activities?

To address the aforementioned issues taking advantage of mobile learning, context-aware learning and ubiquitous learning, yielding a ubiquitous learning environment for diverse educational applications, this study aimed to develop an Environment of Ubiquitous Learning with Educational Resources (EULER) based on RFID, the Internet, a wireless network, embedded systems, and database technologies.

The fundamental concepts of the proposed EULER for outdoor teaching are as follows. Digitized teaching materials are stored in the EULER. The teacher constructs the relationships between teaching materials in the EULER and the RFID codes of RFID tags. The teacher may prepare small information boards with attached RFID tags that they can place at designated locations, allowing students to use handheld devices with RFID readers to request context-aware content from the content server. Students can also collect data, share data, and edit articles at their discretion. Accordingly, teams can work together to solve common problems,
complete assigned tasks, and achieve the goals of collaborative learning (Zurita & Nussbaum, 2004; Zheng, Ogata, & Yano, 2004). Simultaneously, teachers can conduct outdoor teaching and real-time assessment, anytime, anywhere. Ubiquitous computing technology is important for context-aware learning in this learning model. The developed EULER contains rich learning resources and abundant functionality to help teachers develop diverse learning applications anytime, anywhere, even in locations without information presentation capacity. The EULER has the following design features:

- interactivity—virtual classrooms with multiple functions allow teachers to conduct outdoor learning activities easily;
- accessibility—pluralistic learning materials and management mechanisms allow teachers and students to obtain resources easily;
- permanency—learning records management mechanisms allow learning records to be preserved indefinitely;
- collaboration—interactive, mobile, handheld devices help students collect data, exchange information, share experiences, and complete group tasks;
- museum-likeness—a ubiquitous learning model simulates learning in museums;
- context awareness—RFID functions allow teachers to integrate real learning objects (exhibits) and teaching resources to deliver context-aware content at the right time and in the right place.

The rest of this article is organized as follows. Section 2 describes the structure of the EULER. Section 3 describes a full-scale experiment. Section 4 presents and discusses the experimental results. Section 5 draws conclusions.

The EULER

The EULER consists of two subsystems, the MOBILE-Based Interactive Learning Environment (MOBILE) server for use by the teacher and mobile-tools (m-Tools) for students. Figure 1 presents the structure of the EULER. In the case of an outside classroom teachers can use notebooks in which the MOBILE server is installed to conduct outdoor teaching. Before teaching teachers can add teaching materials to the Mobile Content Database (MCDB) and add assessments to the Mobile Assessment Database (MADB). The MOBILE server addresses requests from and responds to students during teaching. The Learning Activity Management (LAM) unit constructs a virtual classroom and supports many learning activities, such as bulletin boards, forums, voting, chatting, homework, assessment, and instruction. Teachers can perform tests using a Mobile Assessment Management (MAM) unit and analyse student performance after the outdoor teaching has been completed. Student learning statuses and records are saved in the Mobile Learning Record Database (MLRDB), which stores the student records, including their assignment grades, reading times, number of discussions in which they have participated, instances of data collection, and instances of information sharing.
The m-Tools system is built on a PDA platform. It has various functions, such as m-Loader, m-Player, m-Capture, m-Sharer, m-Notes, and m-Calendar. The Management Interface (MI) coordinates each tool and stores learning records in the Mobile Database (MDB). For instance, if a student who uses a PDA on a visit to a zoo observes an exhibition that has an RFID tag, then the RFID reader on the PDA detects the internal code of the tag, and the m-Loader then sends this code to the MOBILE server, which in turn downloads context-aware content to the PDA. The student then uses m-Player to browse the contents immediately, and the m-Player simultaneously updates the MDB with the material read by the learner. Additionally, the student uses m-Messages to receive teacher guidance, m-Capture to record videos of the animal, and m-Loader to access additional materials from the MOBILE server. The student can later use m-Notes to compile collected information into articles and m-Sharer to send the articles to the team leader over a wireless local area network (WLAN). The team leader can organize these articles, compile them into a team report, and then send the report to the teacher, achieving collaborative learning. Upon completion, the student can use m-Test to take tests and evaluate his learning achievement. Additionally, m-Calendar can be used to organize personal learning schedules and remind users of homework deadlines and test events.

**Evaluation**

A series of controlled experiments was conducted using the EULER in learning activities for Grade 5 students. After the experiments had been performed a questionnaire survey was given to evaluate the effectiveness of the EULER in improving student learning motivation and effectiveness.
Experimental Method

This study adopted the experimental design for non-equivalent groups. This design requires a pre-test and post-test for an experimental group and a control group. Table 1 presents the experimental design for non-equivalent groups. The experimental group used the EULER while the control group used traditional learning methods. All participant teachers had at least 10 years experience of computer-assisted instruction. Assessments to evaluate student learning effectiveness were designed by participant teachers and updated annually according to instructional requirements. Under these conditions the assessments have superior validity. This study adopted the Cronbach \(\alpha\) coefficient to evaluate the internal consistency reliability of the assessments. The Cronbach \(\alpha\) coefficient ranges between 0 and 1. Nunnaly (1978) stated that 0.7 is an acceptable minimum reliability coefficient. Table 2 reveals that all Cronbach \(\alpha\) values in this experiment exceeded 0.7, indicating the high reliability of the assessments used. Questions in the pre-test were based on students’ prior knowledge and covered the definition, geology, and environment of wetlands and related topics. Questions on the post-test covered what students had learned during the course, including the importance of wetlands to human life and the protection and restoration of wetland ecosystems and wetland creatures. After the experiments were completed, an independent two-sample \(t\)-test was employed to evaluate the learning achievement of the two groups of students.

A questionnaire was administered to 36 students at the end of the experiments to determine the degree of perceived usefulness, ease of use, and attitudes toward use of

Table 1. Experimental design for non-equivalent groups

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of students</th>
<th>Pre-test</th>
<th>Treatment</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>36</td>
<td>Test students’ prerequisite</td>
<td>Apply the EULER</td>
<td>Test knowledge learned on the course</td>
</tr>
<tr>
<td>group</td>
<td></td>
<td>knowledge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control group</td>
<td>36</td>
<td>Test students’ prerequisite</td>
<td>Use traditional</td>
<td>Test knowledge learned on the course</td>
</tr>
<tr>
<td></td>
<td></td>
<td>knowledge</td>
<td>instruction</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Internal consistency reliability of the assessments and questionnaire (\(n = 72\))

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Post-test</th>
<th>Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s (\alpha)</td>
<td>.84</td>
<td>.81</td>
<td>.79</td>
<td>.80</td>
<td>.85</td>
<td></td>
</tr>
<tr>
<td>Group A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.72</td>
</tr>
<tr>
<td>Group B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.73</td>
</tr>
<tr>
<td>Group C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.81</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.83</td>
</tr>
</tbody>
</table>
the EULER. The Technology Acceptance Model (TAM) (Davis, 1986, 1993; Davis, Bagozzi, & Warshaw, 1989) was employed to measure usefulness and ease of use of the system. The TAM is an information system (IS) which models how users come to accept and use a technology. The TAM posits that two particular beliefs—perceived usefulness and perceived ease of use—are of primary relevance. Perceived usefulness is defined as the subjective probability that the use of a given information system increases a user’s performance in an organizational context. Perceived ease of use refers to the degree to which the prospective user expects that the use of the IS is free of effort. A user’s “attitude toward using” is a function of the perceived usefulness and perceived ease of use that directly influences actual usage behavior (Adams, Nelson, & Todd, 1992; Davis et al., 1989; Hendrickson, Massey, & Cronan, 1993; Subramanian, 1994; Szajna, 1994).

The questionnaire survey was administered to all students during the final class. A five-point Likert scale was used for all questions: 1 denotes strong disagreement, while 5 denotes strong agreement. According to Table 2 the Cronbach $\alpha$ of each item exceeded 0.7, indicating that the internal consistency reliability of the survey was satisfied. A one sample $t$-test was applied to analyse the answers to the questionnaire, to determine the usefulness of the proposed EULER, and to determine student learning attitudes.

Participants

This study involved the cooperation of the Affiliated Experimental Elementary School of Taipei Municipal University of Education. The participants included four teachers and 72 Grade 5 students. Students were randomly assigned to the experimental group and the control group, with each group comprising six teams, each with six students.

Course Design

Hybrid instruction, which combines traditional instruction and computer-assisted instruction, has proven successful in many Taiwanese schools. This study adopted this pedagogical approach for the experimental group but used traditional instruction for the control group. The course was divided into four phases. In phase one teachers spent 50% of their teaching time performing traditional teaching in the classroom. In phases 2–4 teachers spent 50% of their teaching time conducting interactive e-learning activities with the experimental group.

Taiwan’s wetlands include various creatures that are worthy of study and discussion. Therefore, this topic was chosen for a course entitled “Taiwan ecosystems.” Problem-Based Learning (PBL) was adopted as the pedagogic strategy, with the problem designated as “How can the gradually disappearing wetland ecosystems in Taiwan be protected and restored?” The advantages of PBL over traditional teaching methods have been well documented and include improving self-directed learning, increasing self-motivation, fostering problem-solving abilities and
improving knowledge application skills (Jones, 1996; Stephien & Gallagher, 1993).
The learning goals of this course were as follows: (1) understanding the natural
environment and creatures in wetlands; (2) understanding the importance of
wetlands; (3) understanding the relationship between creatures and the environment;
(4) understanding the concept and manner of protecting wetland ecosystems. The
main learning purpose of this course is to cultivate the problem-solving and
knowledge construction capabilities of students. The course was designed as follows.

**Phase 1. Traditional learning inside the classroom (weeks 1–8).** Students were divided
into a control group and an experimental group. Teachers administered a pre-test to
the two groups of students before teaching. Teachers adopted traditional instruction
with the two groups of students. Teachers gave test 1 to all of the students at the end
of this phase.

**Phase 2. E-learning and traditional learning inside the classroom (weeks 9–12).** Control
group students employed traditional learning methods while the experimental group
students used the EULER. Teachers assigned homework to both groups. Teachers
gave test 2 to both groups at the end of this phase.

**Phase 3. Problem-based learning outside the classroom (weeks 13–15).** Teachers assigned
a problem-solving project to both groups and conducted a treasure hunt game. The
control group employed traditional learning methods while the experimental group
used the EULER. Students had to complete team project reports. Teachers gave test
3 to both groups at the end of this phase.

**Phase 4. Evaluation (week 16).** Teachers gave grades to project reports and
highlighted outstanding reports. Teachers conducted a post-test and a questionnaire
survey at the end of this phase.

**Learning Activities**

The learning activities of the control group were paper based. Students read the
textbook and used conventional methods to record information and then compiled
the recorded information into a worksheet or report. Face-to-face interaction and oral
communication between teachers and students took place simultaneously.

In contrast, the experimental group adopted the EULER to carry out learning
activities. Indoor teaching was undertaken in the Affiliated Experimental
Elementary School of Taipei Municipal University of Education, while outdoor
teaching was conducted in Guandu Nature Park, a famous wetland in the Taipei
area (Guandu Nature Park, 2004). Teachers administered a pre-test to the two
groups of students in phase 1. They then spent 50% of their teaching time (8
weeks) introducing wetland ecosystems through traditional teaching methods. At
the end of this phase the teachers gave test 1 to all students. In phase 2 25% (four
weeks) of the teaching time was taken up by discussion and in interactions with
students using the EULER. Meanwhile, teachers assigned homework. Students reviewed the course lectures, browsed resources, collected information, shared knowledge, and discussed homework using the EULER. Homework grades were given, and the best homework was shared with students. Teachers gave test 2 to the students at the end of phase 2.

In phase 3 teachers assigned a team problem-solving project and spent 19% of their teaching time (3 weeks) conducting outdoor teaching and a treasure hunt game at Guandu Nature Park. Teachers used notebooks installed with the MOBILE server to conduct learning activities. Each student used a mobile learning device with m-Tools installed to perform the learning activities. Figure 2 depicts the constituents of the ubiquitous learning device, which included a PDA, an RFID reader, a camera, and RFID tags. Teachers prepared a number of information boards, with an RFID tag attached to each. Teachers used the MOBILE server to establish the relationships between the learning materials and the identification codes of the RFID tags and 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, as shown in Figure 3. A student approaching a scenic spot could use the learning device to detect the RFID tag attached to the information board. The detected identification code of the RFID tag was then sent to the teacher’s MOBILE server via a WLAN. The MOBILE server located each student and then sent the context-aware contents to the student’s learning device. Figure 4 illustrates the ubiquitous learning scenario/ubiquitous museum (u-Museum) environment based on RFID, the Internet, mobile computing, and database technologies. On completing a learning unit at a particular scenic spot team members answered a question and then went to the next scenic spot until they had visited all scenic spots. The team that completed the game first was given an
award. Students thus accessed context-aware content related to real creatures, enabling context-aware learning.

Furthermore, under the teacher’s guidance team members used m-Tools to capture images, sound, or video of wetland creatures and retrieved relevant

Figure 3. Map of the treasure hunt game. Each team must visit each scenic spot in the order on the map. The team that completes the visits the fastest wins

Figure 4. The scenario at Guandu Nature Park that uses the EULER. A student near a scenic spot uses a learning device with an RFID reader to request rich context-aware content from the MOBILE server. The experience is like learning in a museum
information from the MOBILE server, which they then compiled into articles. These articles were then transmitted to their team leader to produce a team project report, which was submitted to teachers over a WLAN. Figure 5 depicts examples of learning activities and Figure 6 presents the user interface of the MOBILE server and m-Tools. After all the students had completed their outdoor learning activities and submitted their team project reports using m-Tools the teacher sent the best reports via the MOBILE server to each group. These outcomes were evaluated by peer groups and the teacher. The teacher gave real-time test 3 to students to evaluate their learning performance in this phase.

Figure 5. Snapshots of outdoor teaching in the wetland area. (a) Students use PDAs installed with m-Tools for collaborative learning; (b) two students use a PDA with an RFID reader to request context-aware content

Figure 6. Snapshots of the user interface of the EULER. (a) The interface of the MOBILE server; (b) the interface of m-Tools
A post-test was given to evaluate learning outcomes during the final week in phase 4. A survey was administered after the course was completed. A total of 36 valid questionnaires were submitted, with a response rate of 100%.

**Results and Discussion**

An independent two sample $t$-test was adopted to analyse the learning achievements of two groups of students. The result ($p > .05$) of Levene’s test for equality of variances in Table 3 indicates that the assumption of homogeneity of variances for the two groups is satisfied. Table 4 presents the mean grades and standard deviation of evaluations for each learning activity. Table 5 presents the $t$-test results of evaluations for each learning activity. The effect size was adopted to measure the significance of the difference between the evaluation results of the two groups. Cohen’s $d$ (Cohen, 1992) is an appropriate effect size measure for use in the $t$-test. Cohen’s $d$ is defined as:

$$d = (\text{mean}_1 - \text{mean}_2) / \sqrt{[(\text{SD}_1^2 + \text{SD}_2^2) / 2]}$$

where mean$_i$ and SD$_i$ denote, respectively, the mean and standard deviation of group $i$, with $i = 1, 2$. The values 0.2, 0.5, and 0.8 represent a small, medium, and large effect size, respectively. Teachers distributed a pre-test to both groups of students before the experiments were conducted. The difference between the average grades of the two groups in the pre-test was insignificant ($t = -0.21$, $p > .05$, $d < 0.2$), indicating that the prerequisites of the two groups of students were similar. In test 1, homework (HW), test 2, and test 3 the average grades of the experimental group exceeded those of the control group by at least 10 points, and this difference was significant ($p < .05$, $d > 0.8$), indicating that the effectiveness of the EULER improves learning, perhaps because: (1) the EULER provides rich teaching resources and flexible functions, satisfying context-aware learning applications for teachers; (2) the EULER provides plentiful and convenient learning resources, allowing students to learn at their discretion and independently. In phase 3 the average grade of the experimental group significantly exceeded (by 21 points) that of the control group ($t = 13.83$, $p < .05$, $d > 0.8$), implying that the EULER is useful, allowing students to collect various information, construct knowledge, and complete team work. The use of m-Tools may help students solve problems and stimulate their creativity in computer-supported collaborative learning (CSCL) activities. The average grade of the experimental group significantly exceeded (by 13 points) that of the control group ($t = 6.88$, $p < .05$, $d > 0.8$) in the post-test, indicating that the proposed EULER improves learning achievement, perhaps because the EULER provides a new learning model that effectively increases students’ interest in learning, as well as offering a museum-like experience in outdoor teaching. Additionally, the average post-test grade in the experimental group significantly exceeded that in the pre-test ($t = -14.52$, $p < .01$), as shown in Table 6. This finding also indicates the effectiveness of the EULER.
Table 3. Levene's test for equality of variances

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Test 1</th>
<th>HW</th>
<th>Test 2</th>
<th>Report</th>
<th>Test 3</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>0.65</td>
<td>0.61</td>
<td>1.06</td>
<td>0.05</td>
<td>0.29</td>
<td>7.18</td>
<td>3.60</td>
</tr>
<tr>
<td>Significance</td>
<td>.80</td>
<td>.44</td>
<td>.31</td>
<td>.83</td>
<td>.59</td>
<td>.08</td>
<td>.16</td>
</tr>
</tbody>
</table>

Table 4. Mean grades and standard deviations of evaluations for each learning activity

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Test 1</th>
<th>HW</th>
<th>Test 2</th>
<th>Report</th>
<th>Test 3</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>41.4 ± 10.13</td>
<td>74.5 ± 5.94</td>
<td>86.2 ± 5.03</td>
<td>83.6 ± 7.51</td>
<td>91.4 ± 6.04</td>
<td>85.2 ± 9.24</td>
<td>90.1 ± 7.12</td>
</tr>
<tr>
<td>Control group</td>
<td>42.6 ± 9.97</td>
<td>62.6 ± 7.21</td>
<td>75.2 ± 6.02</td>
<td>65.8 ± 8.13</td>
<td>70.2 ± 6.91</td>
<td>74.6 ± 11.58</td>
<td>76.4 ± 9.55</td>
</tr>
</tbody>
</table>

Table 5. Two-sample \( t \)-test results of evaluations for each learning activity

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Test 1</th>
<th>HW</th>
<th>Test 2</th>
<th>Report</th>
<th>Test 3</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t )</td>
<td>-0.21</td>
<td>7.61</td>
<td>8.43</td>
<td>9.64</td>
<td>13.83</td>
<td>4.23</td>
<td>6.88</td>
</tr>
<tr>
<td>( p )</td>
<td>.833</td>
<td>.001(^a)</td>
<td>.001(^a)</td>
<td>.001(^a)</td>
<td>.001(^a)</td>
<td>.001(^a)</td>
<td>.001(^a)</td>
</tr>
<tr>
<td>Cohen's ( d )</td>
<td>0.119</td>
<td>1.80</td>
<td>1.983</td>
<td>2.274</td>
<td>3.266</td>
<td>1.011</td>
<td>1.626</td>
</tr>
</tbody>
</table>

\(^a\) \( p < .01.\)

Table 6. Dependent \( t \)-test results of pre-test and post-test for experimental group (d.f. = 35)

<table>
<thead>
<tr>
<th>Mean ± SD</th>
<th>( t )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test–post-test pair</td>
<td>-33.81 ± 13.97</td>
<td>-14.52</td>
</tr>
</tbody>
</table>
Figure 7 plots the progress curves of the grades of the two groups, further indicating that the learning of the experimental group is better than that of the control group. In summary, the average grade of the experimental group was higher than that of the control group, indicating that the EULER substantially improves the learning effect of all learning activities except the pre-test. These results are similar to those of Chen et al. (2003, 2005) and Ogata and Yano (2004), which reveal that the application of mobile and ubiquitous technologies in teaching can improve student learning performance.

Table 7 shows the statistical results of the survey on learning attitudes and the acceptance of technologies. The responses to the first item indicate that most

<table>
<thead>
<tr>
<th>Group</th>
<th>Item</th>
<th>Mean ± SD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A1. I think that the user interface of the EULER is friendly</td>
<td>3.53 ± 0.70</td>
<td>.002a</td>
</tr>
<tr>
<td></td>
<td>A2. I think that the system functions of the EULER are convenient and sufficient</td>
<td>3.86 ± 0.76</td>
<td>.001a</td>
</tr>
<tr>
<td>B</td>
<td>B1. Applying the EULER to assist learning can increase my learning interest and motivation</td>
<td>4.08 ± 0.81</td>
<td>.001a</td>
</tr>
<tr>
<td></td>
<td>B2. Applying the EULER to assist learning can increase my learning effect</td>
<td>4.03 ± 0.72</td>
<td>.001a</td>
</tr>
<tr>
<td>C</td>
<td>C1. I like to use the EULER to assist with learning after class</td>
<td>4.31 ± 0.71</td>
<td>.001a</td>
</tr>
<tr>
<td></td>
<td>C2. I hope other courses will also use the EULER to assist instruction and learning</td>
<td>4.11 ± 0.75</td>
<td>.001a</td>
</tr>
</tbody>
</table>

*p < .01.
students think that the EULER is easy to use \( (m = 3.53) \). The responses to the second item indicate that the system functions are convenient and sufficient for learning \( (m = 3.86) \). The third item indicates that the EULER can increase the motivation to learn \( (m = 4.08) \). The fourth item indicates that the EULER improves learning performance \( (m = 4.03) \). The responses to the fifth item indicate that most students like to use the EULER to learn \( (m = 4.31) \). Responses to the sixth item indicate that most students would like to use the EULER on other courses \( (m = 4.11) \). All resulting \( p \) values were under 0.01, indicating that perceived ease of use, usefulness, and attitudes to the use of the EULER were significantly favourable.

Conclusions

This study has constructed an RFID-based, ubiquitous learning environment EULER with effective learning resources and plentiful functions to help teachers develop diverse educational applications in locations that lack information presentation capacity. A case study was performed with the participation of four elementary school teachers and 72 Grade 5 students from the Affiliated Experimental Elementary School of Taipei Municipal University of Education. Outdoor teaching was conducted at the Guandu Nature Park in the Taipei area. PBL, CSCL, and context-aware learning pedagogic strategies were adopted and a series of formative learning activities and a treasure hunt game were employed in 16 week courses. Experimental results show that the average grade of the experimental group exceeded that of the control group by at least 10 points in test 1, homework, test 2, and test 3. The average grade of the experimental group substantially exceeded that of the control group in phase 3 and the post-test, by 21 and 13 points, respectively. The measured effect size reveals that the achievement of the experimental group in all learning activities except the pre-test was significantly better than of the control group. A questionnaire survey was administered following all learning activities. The survey results indicate that most students think that the EULER is easy to use and useful in learning. Therefore, they endorsed the use of the EULER for future learning. These results reveal that the proposed EULER not only increases the motivation of students to learn and improves the effectiveness of learning, but also improves student creativity and ability to explore and absorb new knowledge and solve problems over that provided by traditional learning methods. Additionally, this study shows that RFID technology is useful in providing museum-like learning experiences in context-aware, ubiquitous learning activities.

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References


