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Learning in a u-Museum: Developing a context-aware ubiquitous learning environment

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ABSTRACT

Context-awareness techniques can support learners in learning without time or location constraints by using mobile devices and associated learning activities in a real learning environment. Enrichment of context-aware technologies has enabled students to learn in an environment that integrates learning resources from both the real world and the digital world. Although learning outside of the traditional classroom is an innovative teaching approach, the two main problems are the lack of proper learning strategies and the capacity to acquire knowledge on subjects effectively. To manage these problems, this study proposes a context-aware ubiquitous learning system (CAULS) based on radio-frequency identification (RFID), wireless network, embedded handheld device, and database technologies to detect and examine real-world learning behaviors of students. A case study of an aboriginal education course was conducted in classrooms and at the Atayal u-Museum in Taiwan. Participants included elementary school teachers and students. We also designed and used a questionnaire based on the Unified Theory of Acceptance and Use of Technology (UTAUT) theory to measure the willingness for adoption or usage of the proposed system. The experimental results demonstrated that this innovative approach can enhance their learning intention. Furthermore, the results of a posttest survey revealed that most students' testing scores improved significantly, further indicating the effectiveness of the CAULS.

1. Introduction

The rapid development of wireless network technologies has enabled people to conveniently access the Internet from more diverse locations. Wireless local area network (WLAN) offers an excellent solution for schools wishing to establish internet infrastructure. Additionally, the pervasiveness of handheld mobile devices, such as Tablet PC, PDA and smart phone, has transformed learning modes from e-learning to m-learning. Particularly, compared with traditional classroom learning, m-learning overcomes limitations of learning time and space. Thus, the advantages of m-learning are suitable to apply during authentic learning activities. Recently, the concept of 'context-aware ubiquitous learning' has been further proposed to emphasize the characteristics of learning the 'right content' at the 'right time' and 'right place', and also to facilitate a seamless ubiquitous learning environment that supports learning without constraints of time or place (Ogata & Yano, 2004). The so called 'context-aware ubiquitous learning' (Rogers et al., 2005) thus requires the detection of learner context information and provides learning with different learning content via mobile devices in response to different learning contexts.

Currently, teachers often introduce cultural differences through filmstrips in the classroom, teach outdoors, and conduct exercise experiments to help students in local and aboriginal education courses. Outdoor teaching is widely recognized as the most feasible among these methods; therefore, elementary school teachers in Taiwan teach outdoors frequently (Tan, Liu, & Chang, 2007). However, most outdoor teaching approaches are ineffective because students lack expert assistance and convenient outdoor learning tools. Students often do not learn sufficient or useful knowledge without observing teaching materials carefully in outdoor teaching (Chen, Kao, & Sheu, 2003; Tan et al., 2007). This situation influences the learning achievement of students with authentic activities in outdoor teaching. Therefore, the application of information technology on outdoor teaching has become an attractive research topic (Huang, Chiu, Liu, & Chen, 2011; Huang, Huang, Huang, & Lin, 2012).

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In the past decade, various computer-assisted and web-based learning systems have been constructed to provide a more adaptive learning environment with richness of learning resources (Chu, Hwang, Tsai, & Chen, 2009; Huang, Huang, & Chen, 2007; Tsai, 2009; Wang, 2009). Considerable attention has been focused on novel learning approaches with appropriate educational software tools and convenient environments (Hwang, Tseng, & Hwang, 2008), such as activity theoretical approach (McAvinia & Oliver, 2004), computer scaffolding (Sharma & Hannafin, 2007; Chen, Chang, Chen, Huang, & Chen, in press), Web 2.0 technology (So, Seow, & Looi, 2009), and e-Portfolio (Chen, Wu, & Jen, 2011; Huang & Wu, 2011). These learning approaches have been applied successfully in traditional classroom teaching. However, several researchers and experienced educators have emphasized the importance and necessity of "authentic activities," in which students can work with real-world problems (Baloian, Pino, & Hardings, 2011; Chu, Hwang, Tsai, & Tseng, 2010). Authentic learning activities that integrate content and process offer the opportunity to increase student experience with authentic activities by achieving improved content understanding (So & Kong, 2010). Moreover, in traditional Web-based learning environments, all learning content in a curriculum are sequenced by hyperlinks, but no concrete sequence exists and is without navigation support. Researchers found that an inappropriate navigation support in Web-based learning tends to result in disorientation during learning processes, thereby reducing learning efficacy. Likewise, Web-based training often provides students with less one-on-one attention from the instructor, and the feedback they received is probably unlikely to be face-to-face. Furthermore, the biggest challenge that Web-based learning poses to many students is in maintaining motivation. When the paradigm shifts to context-aware u-learning environments, the navigation supports, real-time interaction, and student motivation will be enhanced because students are learning around actual space rather than cyberspace (Liu & Chu, 2010).

Because of the rapid growth of wireless communication and mobile technology development, mobile learning is becoming a popular approach to learning. The continual development of the Radio-frequency identification (RFID) technique will fulfill ubiquitous learning (u-learning). Improvements in technology and the rapidly declining price trend will expand the scope of future RFID applications. The application of the RFID technique in teaching and learning activities will not restrict this type of learning in a physical classroom, and learning materials will not be textbooks. The RFID technology is able to provide students with sufficient prearranged information whenever they go through the predetermined learning locations (Hwang, Kuo, Yin, & Chuang, 2010). Moreover, the RFID technology may assist the learning system to detect and record the learning behaviors of students in a real environment. This type of sensing technology may enable mobile learning to provide learners with an alternative approach to manage problems in a real-world context, and effectuate the learning system to interact with learners more actively (Chen, in press; Ogata & Yano, 2004). Compared with GPS, WLAN can provide precise location information in both indoor and outdoor environments and has been widely implemented in most public areas and school environments (Kupper, 2005). WLAN positioning is a more suitable method of enabling the development of "context-aware ubiquitous learning" that can provide learning content associated with learning contexts and assists learners in context-based learning in a campus environment. In addition, the WLAN and RFID technologies are synergistically used to provide a platform for a higher-performance positioning process, in which the strong identification capabilities of RFID technology enable increasing the accuracy of positioning systems through WLAN fingerprinting. Thus, the RFID technology would be suitable to apply in the u-Museum environment in this research. Consequently, this study constructed a context-aware ubiquitous learning system (CAULS) based on RFID technology and PDA handheld reader equipment. This study applied a three-tier teaching strategy to improve the teaching and learning process. Moreover, this study also designed learning materials through context-aware interfaces, and subsequently provided personalized learning support for each learner. Finally, this study proposes the outdoor teaching tool CAULS, which is useful for supporting learners in enhancing their motivations and performance with authentic activities.

2. Relevant research

In earlier studies, mobile learning focused on implementing learning systems to "supplement" learners, to learn in authentic learning environments. For example, Chen et al. (2003) designed an outdoor mobile learning activity on birdwatching by using handheld devices to show learning sheets and supplementary materials. Ogata and Yano (2004) proposed JAPELAS and TANGO systems to guide students to learn Japanese in real-world circumstances. These systems may provide students with adequate expressions on the basis of various contexts through mobile devices. Rogers et al. (2005) used mobile devices to allow children to observe and collect data in the woodlands. Consequently, they claimed that digital augmentation was a promising approach to enhance the learning process, especially by encouraging the dovetailing of exploring and reflecting when indoors and outdoors. Currently, researchers have attempted to use sensing or wireless technologies to provide more effective learning tools. Several technique reports or best practices have been proposed from related consulting companies or suppliers of RFID technologies. RFID is a wireless sensor technology based on electromagnetic signal detection. In addition, RFID is an identification system in which an electronic appliance is attached to an item and uses radio frequencies to communicate with other appliances. The two most important components in an RFID system are the RFID tag (an electronic identification device attached to the item to be tracked) and the RFID reader (a device that can sense and extract data from the tag). Once extracted, the RFID reader usually transmits the data to another server/system running edge applications through RFID middleware software that translates reader observations before passing them forward. Several academic studies obtained optimal results in educational experiments; for example, Chen, Chang, Lin, and Yu (2008) used a wireless network, handheld device, and RFID to build a context-aware writing system (C-Writing) in ubiquitous learning environments. As demonstrated by the results, this system attracted the attention of learners and helped them improve learning performance efficiently. Subsequently, Hwang, Yang, Tsai, and Yang (2009) proposed a context-aware ubiquitous learning system with RFID communication and sensing technologies to support researchers who lacked practical experience by using single-crystal X-ray diffraction operations (Hwang et al., 2009). Moreover, Chiou, Tseng, Hwang, and Heller (2010) presented the navigation support problem for context-aware ubiquitous learning, and two navigation support algorithms (Chiou et al., 2010). Their goal was to enhance the efficiency of learning and navigation. As demonstrated by the results, this approach is useful to improve the achievements of learners and to help them use learning resources more efficiently.

In a context-aware ubiquitous learning environment, individual students are guided to learn in a real-world situation with support or instructions from a computer system or using a mobile device to access the digital content via wireless communications. This is where the learning system is able to detect and record the learning behaviors of students in both the real world and the virtual world with the help of the sensor technology (Hwang et al., 2009; Ogata & Yano, 2004). The connection between learner-centered and real-world-situated learning has been shown in the numerous relevant research. For example, Ogata and Yano (2004) developed a system to assist overseas students in Japan to learn Japanese. The students were guided by the u-learning system with PDAs based on their real-world locations. Moreover, several studies have reported the benefits of applying the context-aware u-learning approach, including the promotion of learning motivation (Chiou et al., 2010; Ogata & Yano, 2004) and the improvement of learning effectiveness (El-Bishouty, Ogata, & Yano, 2007; Rogers et al., 2005).

Therefore, the location-aware mobile learning approach extended the applications of location-based learning, outdoor learning, and situated learning, which places learners in real-world learning scenarios (Bamberger & Tal, 2007). This approach also integrates both the real-world and digital-world learning resources from absolute in-field learning into a new learning scenario. To help learners organize and extract their personal knowledge more effectively, designing novel learning middleware tools and learning management systems (LMS) is necessary by considering both real-world and digital-world factors (Hwang, Chu, Shih, Huang, & Tsai, 2010). Is it possible to construct a learning environment to help learners combine the real world and digital world effectively? The empirical evidence on the issue remains mixed (Schiaffino, Garcia, & Amandi, 2008). Therefore, this study attempts to develop a location-aware learning environment with appropriate teaching strategies for offering learners a more authentic learning experience.

3. System design and architecture

In this study, the authentic learning environment was an Atayal museum consisting of six categories of aboriginal artifacts as target objects. Each aboriginal artifact was labeled with an RFID tag, and each student had a handheld device equipped with an RFID reader. In addition, a wireless network was provided to enable communication between the handheld device and the mobile server that operates the learning system. The RFID technology enabled students to navigate these artifacts not only by receiving vocal guidance, but also by obtaining relevant multimedia information through the screen of the handheld device. When students are standing near artifacts, the handheld device detects the RFID tag and plays audio directions relevant to these “trigger points.” This is achieved by placing an RFID receiver with the students; as soon as the handheld device is proximate with the RFID tag, the RFID reader receives the RFID tag unique id and matches it with that of its own database. Subsequently, the relevant artifacts information stored in the database is also transferred to the student’s handheld device. Students who participated in the learning activity were required to observe and recognize the features of the aboriginal artifacts. As they moved around the authentic learning environment, the learning system detected the location of each student by reading and tracking the data from the nearest RFID tag. Consequently, the learning system provided personalized guidance to each student by interacting with them through the handheld device. To achieve optimal teaching and learning, this study proposes three modules in the CAULS system, as shown in Fig. 1. This system is composed of three modules, as discussed in the following sections.

Before conducting the major survey, four respondents who were experts in the field of e-learning and two local aboriginal elders who served in the elementary school were selected to participate in the teaching strategy and content design. Two respondents were e-portfolio development project managers from SUNNET and FormosaSoft, which have not only deployed e-learning systems at hundreds of universities and colleges, but are also pioneers in the development of e-Portfolio systems in Taiwan. The other two respondents were university instructors (different from the authors) who have taught e-learning-related courses and used e-learning systems with their students for over five years. Furthermore, the selected two local aboriginal elders were asked to provide or comment on artifacts that corresponded to the various constructs, including the wording of artifacts, questionnaire, and teaching materials.

3.1. U-learning module (ULM)

The main purpose of the ULM is to allow interactions between learners and course content, and the ULM design is based on the concept of “transformative knowledge” and formative assessment. The ULM provides learning materials for learners to adjust and record functions. The learning process and the PDA handheld reader operation produce a concept map for learning to meet the learning status of learners in the teaching of real-time adjustments and feedback. As shown in Fig. 2, once learners finish studying Unit 1 of the instruction, they subsequently experience their first formative assessment with their PDA handheld reader, and the system calculates their testing scores and

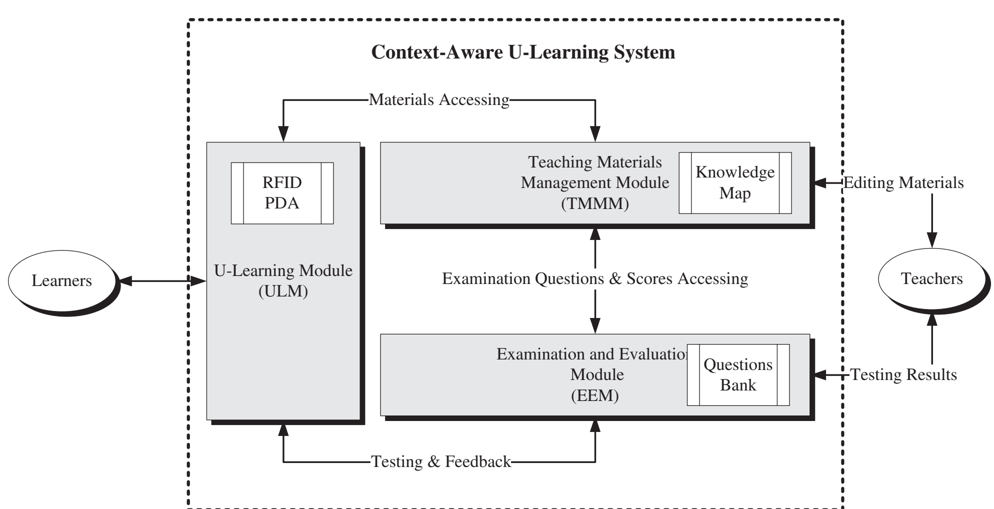

Fig. 1. System architecture.

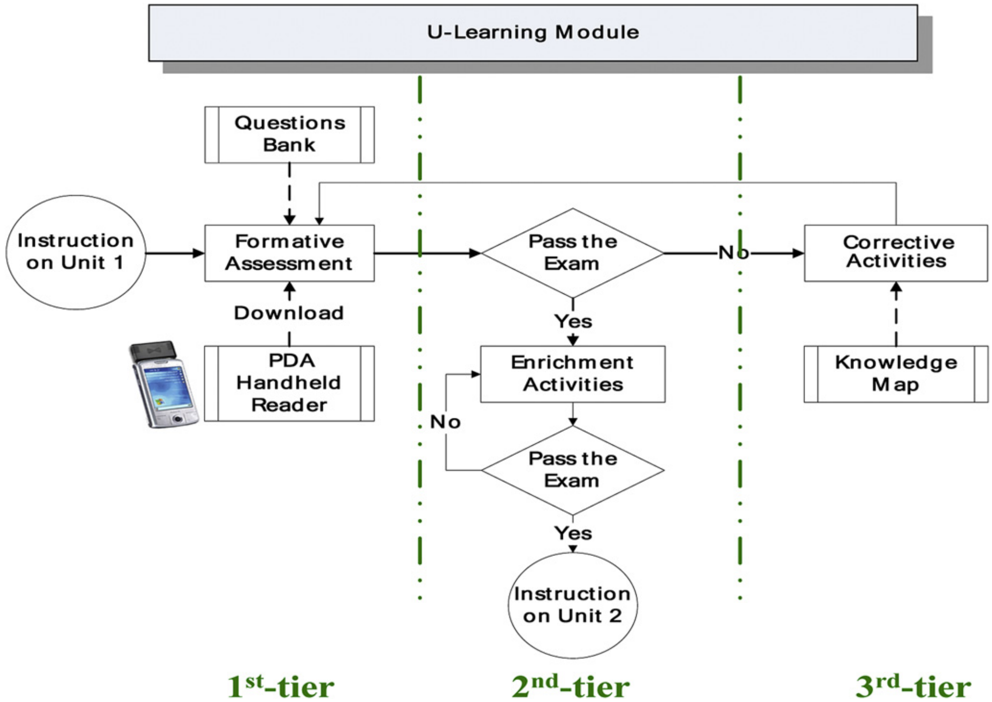

Fig. 2. ULM architecture.

classifies their learning performance. Finally, if learners fail to pass the standard level in Unit 1, the system recommends other appropriate personalized curricula and various materials with the same concepts. The system then transmits the suitable materials to the PDA handheld reader of learners with RFID wireless technology. Conversely, if learners pass the exam in Unit 1, they continue with the additional related topics in enrichment activities. Therefore, learners can relearn the same concepts through various curriculum sequencing and materials in corrective activities with a knowledge map function. When learners complete their corrective activities, they are administered a second formative assessment. This ensures that learners learn the important concepts and prevents them from simply memorizing answers to specific questions from the question bank.

With the support of the RFID technology, the CAULS can detect the location of each student, and guide them to observe and recognize the features of the aboriginal artifact. Moreover, the ULM guides each student in further learning based on their responses to the questions; that is, a three-tier teaching (3T) mechanism was used to evaluate the domain knowledge of the students and guide them to learn based on the evaluation results. The details of the 3T mechanism are provided as follows:

Step 1: Detect the location of the student and send the target aboriginal artifact learning materials.
Step 2: Conduct **first-tier** observations of the target aboriginal artifact:

Execute the formative assessment questions concerning a feature of the target aboriginal artifact from the questions bank and guide students to observe that feature.

Step 3: Execute the enrichment activity or corrective activity
- Step 3.1: If the student correctly recognizes the feature of the aboriginal artifact and passes the exam:
  - Step 3.1.1: Present the **second-tier** question that asks the student an advanced or in-depth concept related to the answer. This enrichment activity enhances the learning concepts and memories.
  - Step 3.1.2: If the student fails to answer the **second-tier** question correctly, present hints or supplementary material to the student and return to Step 3.1.1.
  - Step 3.1.3: If the student answers the **second-tier** question correctly, proceed to Step 5.
- Step 3.2: If the student fails to recognize the feature of the aboriginal artifact and fails the exam:
  - Step 3.2.1: Present the **third-tier** question that provides the student with a comparative aboriginal artifact or in-width concept related to the answer. This corrective activity demonstrates the difference of a particular feature between the original target and comparative target.
  - Step 3.2.2: Ask the student to execute the formative assessment again. If the student fails to recognize the feature correctly, present the corrective materials to the student.
  - Step 3.2.3: If the student answers the **third-tier** question correctly, return to Step 3.1.1.

Step 4: Repeat Step 3 until the student correctly answers the questions and has been qualified with the relevant knowledge in the target unit.
Step 5: Guide the student to visit the next target aboriginal artifact and repeat Steps 2–4 until all target aboriginal **artifacts** are observed.

In the **1st-tier** question, for example, students observe the weapon and hunting equipment (target object) "Mountain knife" and describe its "blade" as "Curved." If the student answers the question correctly (i.e., the blade of the "Mountain knife" is "Curved"), the CAULS asks the student to answer the **2nd-tier** question. In this illustrative example, the **2nd-tier** question could be the length of the mountain knife or other in-depth concepts. If the student's answer is incorrect, the CAULS provides corresponding learning materials of the same concept to the student, and then asks the student to answer the question again.

Conversely, if the student's answer is "Straight" and CAULS compares the answer with the correct answer provided by the teacher (i.e., "The blade of the mountain knife is curved"), the CAULS determines the student's answer to be incorrect. Consequently, the CAULS attempts to find a comparative weapon with a "blade" that is "Straight" from the database. Assume that another weapon, "Head-hunting knife," has this feature, that is, its "blade" is "Straight." In the **3rd-tier** question, students are guided to observe "Head-hunting knife" and compare its "blade" with that of the "Mountain knife."

Thus, in this three-tier teaching strategy, the **1st-tier** questions are designed to guide individual students to cultivate careful observation skills, whereas the **2nd-tier** questions aim to enhance the learning concepts with in-depth learning to explain what students have observed. The objective of the **3rd-tier** questions is to demonstrate the difference of a particular feature between the original target and comparative target. The goal is to provide students with a comparative aboriginal artifact, and not simply offer a direct and limited answer, but deliver background information for broader and contextual learning.

3.2. Teaching materials management module (TM^3)

The knowledge map concept of this module is mainly a conceptual map application in management modules of teaching materials. In addition, a knowledge map is akin to a repository of a teaching material collection with appropriate structures. A teaching material is considered an aggregate of topic characteristics, including a topic name and its variances, occurrences, and the degree of difficulty in associations with other topics. The knowledge map links topics to enable navigation between them. This capability can be used for curricula assembly, and for supporting the personalized learning process through the proposed methodology. Therefore, teaching units must be able to use the knowledge map and require teaching units from experts on the concept of knowledge and constructs the test of each teaching unit assessment, which is performed by the learner formative tests (pretest) for ease of degree parameters. Finally, through the process of constructing the database depicted in Fig. 3, a course curriculum and the corresponding ease of information are provided to the action of the ULM and the use of PDA handheld readers. Therefore, the TM^3 is based on various concepts related to management and storage. First, the knowledge map of this module is the main application of the concept of teaching units. Second, this module selects the most consistent target condition or teaching materials for teaching. Subsequently, the learning process forms a personalized learning path and assessment for learning. Therefore, the TM^3 can use the knowledge map, and requires expert knowledge for teaching the concept of unit analysis.

3.3. Examination & evaluation module

The Examination & Evaluation Module (EEM) is a crucial measure of the effectiveness of ubiquitous learning tools through the questions bank function. For learning through the assessment of EEM, it provides information for action of the ULM for courses and tests to adjust weight parameters. This module provides a personalized learning process and test assessment records. Curriculum sequencing is a well-established technology in the field of intelligent tutoring system (ITS). The benefit of curriculum sequencing is to generate

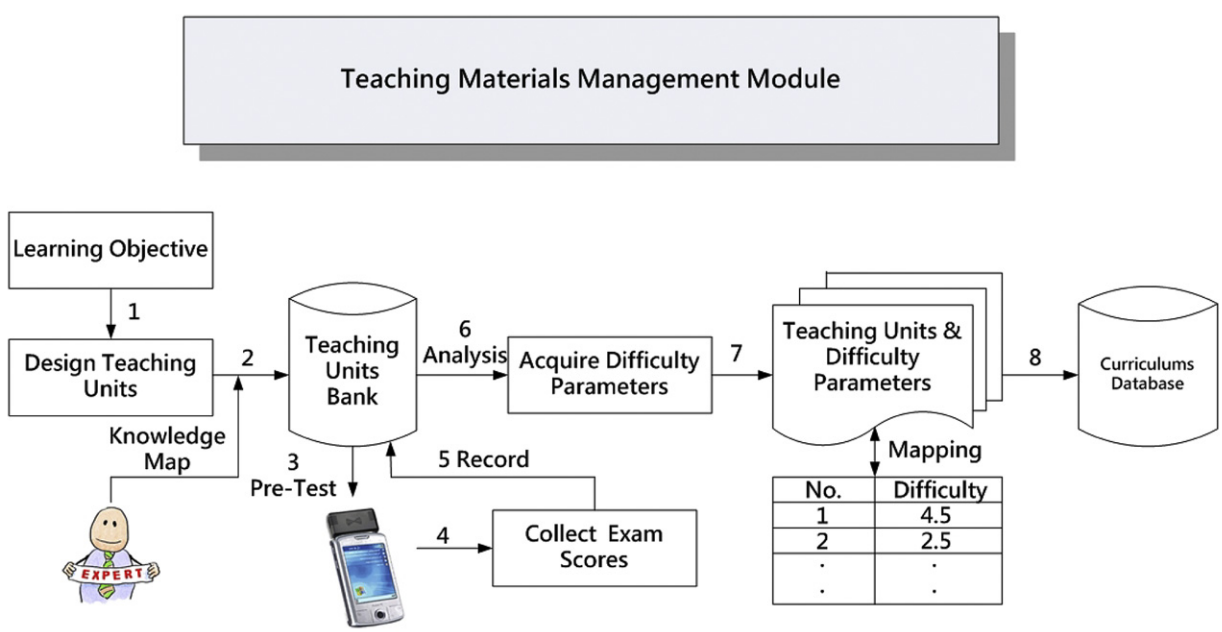

Fig. 3. TM^3 architecture.

a personalized learning course for each student by selecting optimal teaching materials dynamically. Therefore, the proposed approach is based on a formative exam to collect incorrect learning concepts of learners through computerized adaptive testing (CAT) from the questions bank. Thereafter, the EEM is employed to construct a near-optimal learning path according to these incorrect response patterns of the formative exam and search the relevant teaching materials from the curricula database based on the curriculum difficulty degree. Finally, this study assumed that the proposed CAULS supports learners in enhancing learning motivations and learning performance. The process of the EEM is shown in Fig. 4.

4. Evaluation

A series of controlled experiments were conducted using the CAULS in learning activities for Grade Six students. After the experiments were performed, a questionnaire survey was provided to evaluate the effectiveness of the CAULS in improving student learning motivation and effectiveness.

4.1. Experimental method

This study used the experimental design for non-equivalent groups. This design requires a pretest and posttest for an experimental group and a control group. The experimental group used the CAULS, whereas the control group used the tour-based u-learning method. In this study, the tour-based u-learning method has no assistant of the CAULS, and the control group students used the PDAs from one artifact to another and estimated the stay time of each artifact by themselves. All participant teachers had at least 10 years of experience in computer-assisted instruction. Assessments to evaluate student learning effectiveness were designed by participant teachers and updated annually according to instructional requirements. The assessments have superior validity under these conditions. This study used the Cronbach's α coefficient to evaluate the internal consistency reliability of the assessments (Mehrens & Lehmann, 1987). The Cronbach's α coefficient ranges between 0 and 1. Nunnaly (1978) stated that 0.7 is an acceptable minimal reliability coefficient. Table 1 shows that all Cronbach's α values in the experiment exceeded 0.7, indicating the high reliability of the assessments. Questions in the pretest were based on the prior knowledge of students and covered the definition of aboriginal culture, its traditions and artifacts, and related topics. Questions on the posttest covered the content students learned during the course, including the importance of aboriginal culture and the protection and promotion of its traditions and artifacts. After the experiments were completed, an independent two-sample *t* test was used to evaluate the learning achievement of the two groups of students.

A questionnaire was administered to 40 students at the end of the experiments to determine the degree of performance expectancy, effort expectancy, social influence, and facilitating conditions toward use of the CAULS. The Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, Morris, Davis, & Davis, 2003) was used to measure the willingness for adoption or usage of the novel technology. The UTAUT is an information system (IS) that extends the original Technology Acceptance Model (TAM) model (Davis, 1986, 1993), and investigates the acceptance and use of a technology by users. The UTAUT posits that four particular beliefs are of relevance, as follows: performance expectancy, effort expectancy, social influence, and facilitating conditions. Performance expectancy is defined as the degree to which people believe that using the system will help them attain gains in job performance. Effort expectancy is defined as the degree of ease associated with the use of the system. Social influence is defined as the degree to which people perceive that other important people believe they should use the new system. Facilitating conditions are defined as the degree to which people believe that an

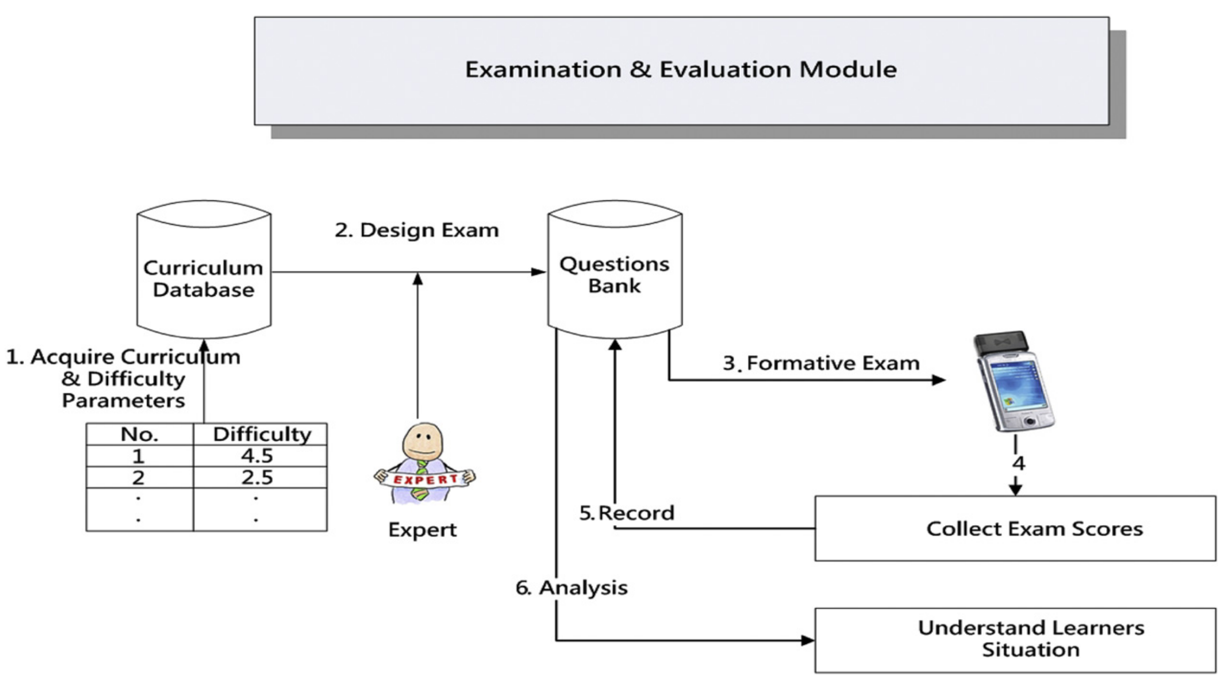

Fig. 4. EEM architecture.

Table 1
Internal consistency reliability of the assessments and questionnaire ($n = 80$).

	Pre-test	Comprehension test	Post-test	Questionnaire	
Cronbach's α	0.86	0.82	0.87	Performance expectancy	0.87
				Effort expectancy	0.85
				Social influence	0.88
				Facilitating conditions	0.86
				Total	0.87

organizational and technical infrastructure exists to support use of the system. The questionnaire survey was administered to all students during the final class. A 5-point Likert scale was used for all questions, ranging from 1 (*strong disagreement*) to 5 (*strong agreement*). 0, Cronbach's α of each item exceeded 0.7, which indicates that the internal consistency reliability of the survey was satisfied. A sample t test was applied to analyze the answers to the questionnaire, to determine the adoption willingness of the proposed CAULS, and to determine student learning attitudes.

4.2. Participants and learning activities design

This study involved the cooperation of the Meiyuan and Wenshui Elementary School of Miaoli County, an area in northwestern Taiwan with a considerable indigenous population. The participants included 4 teachers and 80 Grade Six students. Students were randomly assigned to the experimental group and the control group.

Taiwan's aboriginal tribes include various cultures that are worthy of study and discussion. Therefore, this topic was chosen for a course entitled "Traditional culture and artifact of the Atayal tribe." The learning goals of this course were as follows: (1) understanding the natural environment and daily living in the Atayal tribe; (2) understanding the importance of traditional culture of the Atayal tribe; (3) understanding the relationship between Atayal aboriginal religion and the environment; and (4) understanding the concept and manner of protecting and promoting traditional culture and artifact of the Atayal tribe. The main learning purpose of this course was to cultivate problem-solving and knowledge construction capabilities of students. The course was designed as described in the following paragraph.

Fig. 5 shows the chronology of the research. In Phase 1, the learning activities of the experimental group and control group were paper based. First, all students were required to complete a pretest, which evaluated their prior knowledge on the aboriginal artifact. Subsequently, teachers were guided to provide classification knowledge of the aboriginal artifact. They introduced the artifacts in the aboriginal tribes through traditional teaching methods. Face-to-face interaction and oral communication between teachers and students occurred simultaneously in the classroom. Students read the textbook and used conventional methods to record information into notes or a report. This experiment contained six learning objects, namely "clothes," "weapon and hunting equipment," "grain face," "daily use equipment," "ballad," and "musical instruments." After receiving the fundamental knowledge of the artifact in the aboriginal tribe course (two weeks), all

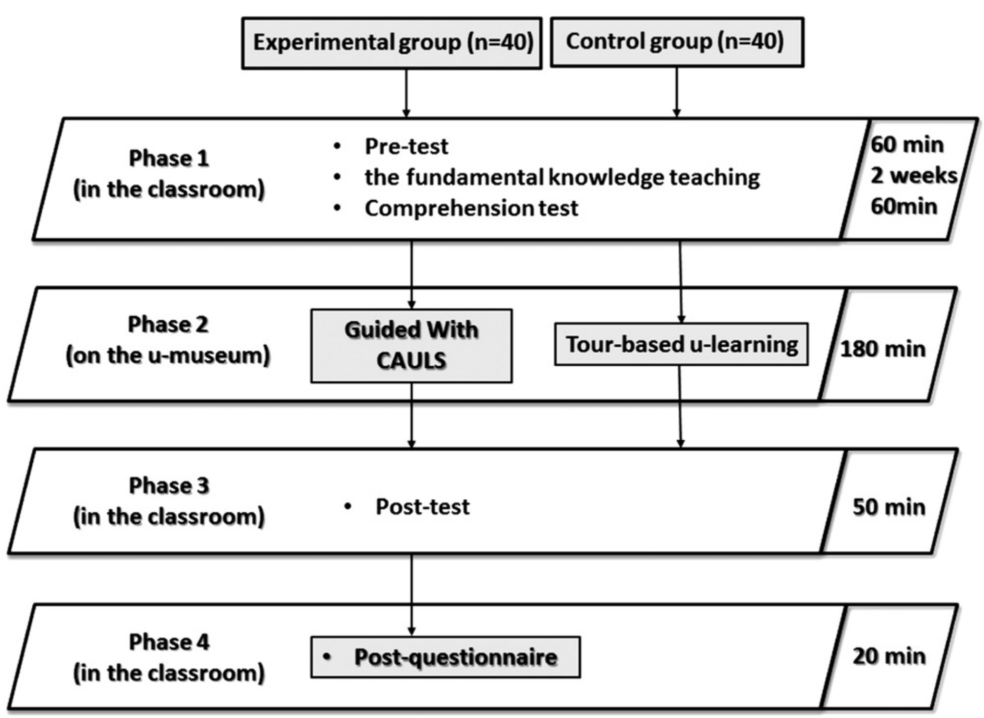

Fig. 5. The chronology of the research.

the students were asked to complete a comprehension test. They spent nearly 1 h answering the test items, which were used to evaluate their basic knowledge on the aboriginal artifact.

In Phase 2, outdoor teaching was conducted in the Atayal u-Museum, a famous aboriginal museum in the Miaoli area. Students in the experimental group were arranged to observe and compare the features of six artifacts on the u-Museum using the CAULS. Conversely, the students in the control group were guided to observe the artifacts through the tour-based u-learning approach. Subsequently, the experimental group learned with PDAs equipped with an RFID reader, with which the CAULS can detect the location of each student, guide them to target artifacts, and provide them with relevant learning materials as soon as they approach a target artifact. This stage required approximately 180 min for each group. In Phase 3, after conducting the outdoor learning activity, students in two groups were asked to complete a posttest (50 min). The intervention group students were asked to answer a post-questionnaire (20 min) in the classroom in Phase 4.

4.3. Learning activities

Teachers used notebooks installed with the CAULS mobile server to conduct learning activities. Each student used a mobile learning device with m-Tools installed to perform the learning activities. Fig. 6 shows the constituents of the ubiquitous learning device, which included a PDA, an RFID reader, and RFID tags. Teachers prepared a number of information boards, each with an attached RFID tag. Teachers used the CAULS mobile server to establish relationships between the learning materials and the identification codes of the RFID tags, and placed the information boards near the corresponding aboriginal artifacts. A student approaching an aboriginal artifact can use the learning device to detect the RFID tag attached to the information board. The detected identification code of the RFID tag was subsequently sent to the CAULS mobile server of the teacher by a WLAN. The CAULS mobile server located each student and subsequently sent the context-aware content to the learning device of the student. After completing a learning unit at a particular aboriginal artifact, students answered a question and subsequently proceeded to the next topic of aboriginal artifact until they passed the related exam. Thus, students accessed context-aware content related to aboriginal artifacts, enabling context-aware learning.

In Phase 3, a posttest was administered to evaluate learning outcomes after the outdoor teaching and learning activities in the u-Museum. A survey was administered after the course was completed in Phase 4. Forty valid questionnaires were submitted, with a response rate of 100%.

4.4. Results and discussion

Table 2 displays the t test results of evaluations for each learning activity, and Table 3 shows the mean grades and standard deviation of evaluations for each learning activity.

The “effect size” is used to measure the significance of the difference between the evaluation results of the two groups. In advance, Cohen’s d has two advantages over other effect size measurements. First, its calculation enables an immediate comparison to increasingly larger numbers of published studies. Second, Cohen (1992) suggested that effect sizes of 0.20 are small, those of 0.50 are medium, and that

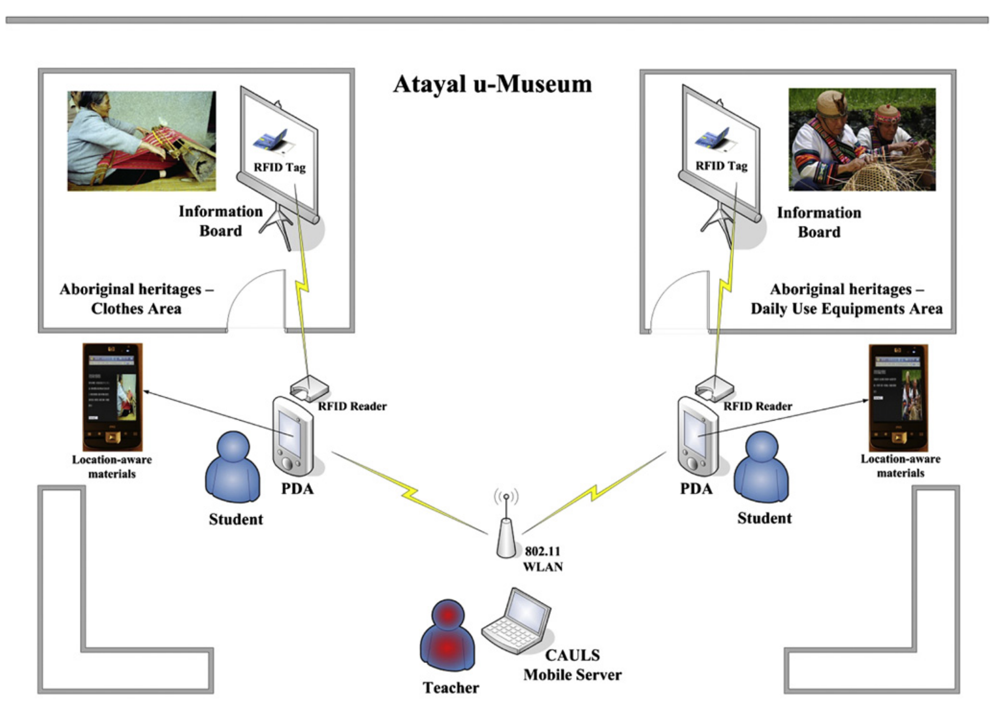

Fig. 6. The learning scenario in the Atayal u-Museum.

Table 2
Two-sample *t* test results of evaluations for each learning activity.

	Pre-test	Comprehension test	Post-test
t	−0.635	0.099	8.493
p	0.527	0.922	0.001*
Cohen's d	0.142	0.022	1.901
Hedges's $\hat{g}$	0.140	0.021	1.883

*$p < .01$.

Table 3
Mean grades and standard deviations of evaluations for each learning activity.

	Pre-test	Comprehension test	Post-test
Experimental group	44.10 ± 7.45	62.65 ± 6.23	87.50 ± 4.78
Control group	45.20 ± 8.02	62.50 ± 7.32	74.75 ± 8.19

those of 0.80 are large, and enable us to compare an experiment's effect size results to known benchmarks. If the effect size is insignificant (means smaller than 0.2), this indicates that the prerequisites of the two groups of students is similar. Conversely, the prerequisites of the two groups of students is significantly different when the effect size is larger than 0.8. However, the disadvantages of Cohen's d are unequal sample size problems and not considering handling sample size (Hedges & Olkin, 1985). Therefore, this study also used Hedges's $\hat{g}$ to assess and evaluate the appropriate effect size. The $\hat{g}$ values 0.2, 0.5, and 0.8 represent a small, medium, and large effect size, respectively. Then, teachers distributed a pretest and comprehension test to both student groups before the experiments were conducted. As shown in Table 2, the t test between these two groups in the pretest ($t = -0.635$, $p = .527$, $d = 0.142$, $\hat{g} = 0.140$) and comprehension test ($t = 0.099$, $p = .922$, $d = 0.022$, $\hat{g} = 0.021$) were non-significant, indicating that the prerequisites of the two groups of students were similar. As shown in Table 3, the average grades in Phase 1 between the experimental group (44.10 ± 7.45) and control group (45.20 ± 8.02) were no more than 2 points in the pretest. Therefore, the grades of the pretest demonstrated that these two student groups were similar and lacked sufficient prior knowledge on aboriginal artifacts. Moreover, the grades of the comprehension test demonstrated that these two groups of students were also similar, and the average grades between the experimental group (62.65 ± 6.23) and control group (62.50 ± 7.32) were also no more than 2 points. The results showed the traditional teaching environment and materials did not provide sufficient and convenient learning resources to improve the learning performance of students.

As shown in Table 2, the t test between these two groups in the posttest ($t = 8.493$, $p < .05$, $d > 0.8$,$\hat{g} > 0.8$) were significant, indicating that the prerequisites of the two student groups were not similar. Furthermore, as shown in Table 3, the important finding is the average grades in Phase 2 of the experimental group (87.50 ± 4.78) exceeded by 12 points by that of the control group (74.75 ± 8.19) in the posttest, indicating that the proposed CAULS improves learning achievement, which may be attributed to the following: (1) the CAULS provides abundant teaching resources and flexible functions, satisfying context-aware learning applications for teachers; and (2) the CAULS provides sufficient and convenient learning resources, allowing students to learn at their discretion and independently. In summary, the average grade of the experimental group was higher than that of the control group, indicating that the CAULS substantially improved the learning effect. These results revealed that the application of mobile and ubiquitous technologies in teaching can improve student learning performance.

Table 4 shows the statistical results of the survey on learning attitudes and the acceptance of technologies toward the CAULS. The responses to the first perspective indicate that most students think that the CAULS is useful (mean = 4.32), reduces learning time (mean = 4.12), and improves learning performance (mean = 4.28). The responses to the second perspective indicate that the system functions are convenient and sufficient for learning (mean = 3.84), improves self-efficacy (mean = 4.08), and is easy to use (mean = 4.26). The third perspective indicates that the CAULS can be promoted by social norm (mean = 4.66), social cognition (mean = 4.31), and fundamental social infrastructure (mean = 4.12). The responses to the fourth perspective indicate that most students have the necessary resources with CAULS to learn (mean = 3.74), sufficient knowledge with CAULS to learn (mean = 3.82), and with profession to ask (mean = 4.62). All resulting p values were under 0.01, indicating that performance expectancy, effort expectancy, social influence, and facilitating conditions to the use of the CAULS were favorable.

Table 4
Statistical results of questionnaire.

Perspective	Item	Mean ± SD	p
Performance expectancy	I would find the CAULS useful in my learning.	4.32 ± 0.64	.001*
	Using the CAULS enables me to accomplish tasks more quickly.	4.12 ± 0.76	.001*
	Using the CAULS increases my learning more effective	4.28 ± 0.66	.001*
Effort expectancy	My interaction with the CAULS would be clear and understandable.	3.84 ± 0.70	.001*
	It would be easy for me to become skillful at using the CAULS.	4.08 ± 0.72	.001*
	Learning to operate the CAULS is easy for me.	4.26 ± 0.75	.001*
Social influence	Classmates who influence my behavior think I should use the CAULS.	4.66 ± 0.33	.001*
	Classmates who are important to me think I should use the CAULS.	4.31 ± 0.67	.001*
	In general, the course has supported the use of the CAULS.	4.12 ± 0.71	.001*
Facilitating conditions	I have the resources necessary to use the CAULS.	3.74 ± 0.67	.001*
	I have the knowledge necessary to use the CAULS.	3.82 ± 0.76	.001*
	Teacher is available for assistance with CAULS difficulties.	4.62 ± 0.36	.001*

*$p < .01$.

5. Conclusion

This research proposes a context-aware ubiquitous learning environment based on the proposed ULM for personalized situated learning with a PDA handheld reader, TM^3 for personalized learning path, and EEM for personalized learning situations and summative assessment analysis. A case study was performed with the participation of 2 elementary school teachers and 80 Grade Six students from the Meiyuan and Wenshui Elementary School of Miaoli County, an area in northwest Taiwan with a considerable indigenous population. Outdoor teaching was conducted at the Atayal u-Museum in the Miaoli area. Experimental results revealed that the average grade of the experimental group exceeded that of the control group by at least 12 points in the posttest. The measured effect size in the posttest shows that the achievement of the experimental group in learning activities was superior to that in the control group. The questionnaire survey results indicate that most students think that the CAULS system is easy to use and is useful in learning. Therefore, they endorsed the use of the CAULS for future learning. These results reveal that the proposed CAULS increases the motivation of students to learn and improves the effectiveness of learning, and also enhances student creativity and their ability to explore and absorb new knowledge and solve problems more than when using traditional learning methods. In addition, this study demonstrated that RFID technology is useful in providing museum-like learning experiences in context-aware, ubiquitous learning, and authentic activities.

This empirical study has several limitations. First, sampling was conducted only in the Meiyuan and Wenshui Elementary School of Miaoli County, an area in northwestern Taiwan with a considerable indigenous population. We recommend that the scope of future studies be expanded to include more people or other aboriginal races to avoid the concerns that resulted from this sample. Second, the questionnaire survey also showed that the proposed approach was able to provide more interesting learning scenarios to students, fostering a positive attitude toward learning that improved significantly, which was even a challenging task for those experienced teachers. Third, we adopted two classes as the experimental and control groups in this research. In addition, we used the internal consistency reliability method to void bias and ensure equivalence of these samples. Thus, further statistical analysis and study is recommended. Fourth, to avoid the Hawthorne Effect on experimental groups, we used the wireless techniques to construct the context-aware u-learning environment and reduced human intervention factors. Therefore, we allowed students to achieve in a self-paced learning environment. However, other models, such as the observation survey, could be included to enhance the explanatory capacity and enhance the comprehensiveness of the study. It is worth attempting to apply the proposed novel approach to the learning activities of other courses in the future. Finally, it is important to investigate how to improve the quality of the context-aware u-learning system for the enhancement of learner benefits.

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