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The design and implementation of a meaningful learning-based evaluation method for ubiquitous learning

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If ubiquitous learning (u-learning) is to be effectively developed and feasibly applied to education, it is necessary to evaluate its effectiveness. Yet to achieve a sound evaluation, a particular paradigm must be employed to fit the problem domain. Toward this end, the authors of this study have adopted a meaningful learning paradigm. Meaningful learning is often regarded as the ultimate learning status for a learner, regardless of the learning environment. Interestingly, several characteristics of u-learning are also linked to attributes of meaningful learning. For example, both u-learning and meaningful learning emphasize the authentic and active of the learning activity. Therefore, it is important to investigate the applicability of a meaningful learning paradigm for evaluating the efficacy of u-learning. The method proposed here evaluates u-learning along both macro and micro aspects, and in an effort to make u-learning more sustainable. By employing a case study, we demonstrate the feasibility of our approach by showing the advantages and disadvantages that are common to both u-learning and meaningful learning. Moreover, we also provide suggestions for instructors and designers so that they can promote the quality of u-learning.

1. Introduction

Advances in ubiquitous computing and context-aware technologies have furnished instructors with an opportunity to engage in novel educational processes (Hwang, Tsai, & Yang, 2008; Liu, 2007) that alter the ways in which students learn (Hall & Bannon, 2006; Huang, Kuo, Lin, & Cheng, 2008). Along with this trend, we are also seeing an increase in ubiquitous learning (u-learning)-related research. According to these researches, the u-learning environment can provide an interoperable, pervasive, interactive, and seamless learning architecture to integrate, connect, and share learning resources among appropriate identities (Huang, Huang, & Hsieh, 2008; Ogata, Saito, Martin, & Yano, 2008; Peng, Chou, & Chang, 2008; Yang, 2006). U-learning has been extensively investigated and applied to various fields, such as computer science, linguistic, nature science, and so on (Chen & Li, 2010; Lan, Sung, & Chang, 2007; Liu, Tan, & Chu, 2009; Wurst, Smarkola, & Gaffney, 2008). Several studies mention that learners could accept this learning approach and that it can enhance learning performance and motivation (El-Bishouty, Ogata, & Yano, 2007; Sharples, 2000). However, learners' learning should be meaningful except increasing learning effects and motives, the materials and content that they learned will be transferred into their knowledge and skills (Jonassen, 1995). Since u-learning is an emerging learning method, the meaning of such a novel technology should be examined when it is applied to learning. Scholars are also of the opinion that the quality of learning systems can be advanced through analyzing and evaluating them (Mangina & Kilbride, 2008; Martínez-Torres et al., 2008; Oral, 2008; Toral, Barrero, & Martínez-Torres, 2007). Therefore, the major purpose lies in evaluating if these u-learning systems help learners achieve meaningful learning in order to ensure the application of u-leaning being meaningful and valuable in education.

One of the most important learning outcomes of u-learning is the achievement of meaningful learning (Chen, Chang, Lin, & Yu, 2009; Jeng, Wu, Huang, Tan, & Yang, 2010). Meaningful learning can be defined as a process in which learners actively relate new information to their own previous knowledge (Ausubel, 1963). Several studies have pointed out that active, authentic, constructive and cooperative

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learning activities can induce students to achieve meaningful learning (e.g., Grabe & Grabe, 2007; Jonassen, 1995; Karppinen, 2005). In addition, scholars have also described the following potential pedagogical benefits of u-learning: enhanced peer interaction, support for learning in authentic situations, support for self-regulated learning, and the active provision of personalized services (Hwang et al., 2008; Ogata, Saito, Paredes, Martin, & Yano, 2008; Peng et al., 2008; Yang, 2006). Moreover, these benefits seem to facilitate the development of meaningful learning.

Although u-learning has the potential to support students to achieve meaningful learning, earlier study (e.g., Liu, 2007) unveiled that learning with innovative technologies does not automatically benefit from these technologies. When designing a technology-supported learning environments and learning activities, evaluation is required to help designers improve the environments so as the activities in it (Jeremić, Jovanović, & Gašević, 2009; Mangina & Kilbride, 2008; Oral, 2008). For the sake of progress in the field, it seems reasonable that a meaningful learning paradigm could be employed to evaluate u-learning. However, a sound way of evaluating whether u-learning environments and activities achieve meaningful learning has yet to be established. Therefore, the design and development of a meaningful learning-based evaluation for ubiquitous learning becomes an important issue for research.

In this work, we aim to design the model, procedures, and tools of meaningful learning-based evaluation method for u-learning, and then evaluate two u-learning systems to realize this evaluation and its effectiveness.

The remainder of this article is organized as follows: Section 2 introduces the rationale for a meaningful learning-based evaluation of u-learning; Section 3 describes the design of a meaningful learning-based evaluation method; Section 4 provides a detailed description and two u-learning systems of the evaluation method applied; and finally, we conclude with a discussion of the implications of this work for future study.

2. The rationale of meaningful learning-based evaluation for ubiquitous learning

2.1. Meaningful learning

Meaningful learning approaches emerged from Ausubel's (1963) study of cognition and learning. Meaningful learning emphasizes students' acquisition of new information and its linkages to previous experiences and knowledge in the formation of personal and unique understandings (Rendas, Fonseca, & Pinto, 2006; Viola, Giretti, & Leo, 2007). Jonassen (1995) has stipulated that any pedagogically significant use of technology must allow learners to engage in meaningful learning. Recently, several studies have tried to use information or communication technologies to support the achievement of meaningful learning (e.g., Karppinen, 2005; Rendas et al., 2006; Rick & Weber, 2010).

After decades of research, various elements of meaningful learning have been proposed. Table 1 lists characteristics of meaningful learning selected from previous studies (Grabe & Grabe, 2007; Jonassen, 1995; Karppinen, 2005). Of the three studies presented, all have the following four characteristics in common: *active*, *authentic*, *constructive*, and *cooperative*. Ultimately, these characteristics became the dimensions upon which our evaluation is based. We defined these characteristics as follows: *active* means that learners are dynamic, that they assume active roles in learning activities; *authentic* means that learners construct knowledge from situated and authentic learning activities; *constructive* means that learners accommodate new ideas to their prior knowledge/experiences (Lin, Lin, & Huang, 2011); and *cooperative* means that learners are encouraged to solve the problems/tasks together with their peers (Huang, Huang, & Yu, 2011). Again, this study adopted these four characteristics of meaningful learning as the principal dimensions of a meaningful learning-based evaluation method for u-learning.

2.2. Ubiquitous learning

Recent advances in ubiquitous computing and wireless technologies have initiated new trends in the field of learning. Earlier studies (Hwang et al., 2008; Ogata et al., 2008; Yang, 2006) suggested that novel technologies such as ubiquitous computing, context-aware computing, and sensor networks can lead to u-learning. Jones and Jo (2004) suggested that u-learning refers to any situation in which students can become completely immersed in the learning process or learning activity. In education, u-learning represents the ability to perceive both the situation and the states of the learners in order to provide them with adaptive assistance (Huang, Lin, & Cheng, 2010; Hwang et al., 2008; Ogata et al., 2008). In addition, Yang (2006) notes that u-learning environments provide a context-aware, interoperable, pervasive, and interactive learning architecture that integrates, connects, and shares learning resources among the appropriate identities.

U-learning environments seem to have the potential for considerable positive impact on learners. However, how do we develop high quality u-learning environments? Many researchers have suggested that evaluation is the way to improve the quality of technology-supported learning environments (Mangina & Kilbride, 2008; Martínez-Torres et al., 2008; Oral, 2008; Toral et al., 2007). According to some research on u-learning evaluation, the application of u-learning is helpful to increase learning effects (El-Bishouty et al., 2007; Huang, Huang et al., 2008; Huang, Kuo et al., 2008; Yang, 2006). Moreover, some researchers suggested that u-learning environments could encourage a learner's motivation (Hwang, Chu, Lin, & Tsai, 2011; Hwang, Kuo, Yin, & Chuang, 2010). However, Jonassen (1995) argued that learners' learning had better be meaningful except being able to increase learning effects and motives, so that the materials and content that learners learned could be transferred into those learners' knowledge and skills. Since u-learning is an emerging learning method, it is necessary to evaluate if such a novel technology is meaningful when it is applied to education.

Table 1
Characteristics of meaningful learning in earlier studies.

Characteristics selected	Jonassen (1995)	Karppinen (2005)	Grabe and Grabe (2007)
(a) Active	Active	Active	Active
(b) Authentic	Authentic	Authentic	Authentic
(c) Constructive	Constructive	Constructive	Constructive
(d) Cooperative	Cooperative	Cooperative	Cooperative
	Intentional	Guided emotionally	Integrated

Table 2
Characteristics, definitions and functions of u-learning.

Characteristics	Definitions	Example functions
Urgency of learning need	U-learning environments can be used for an urgent learning matter.	• Keyword searches • Online problem diagnoses
Initiative of knowledge acquisition	U-learning systems provide information, shortening students' request times.	• Material presentations • Study guidance
Interactivity of learning process	Students can effectively communicate with peers, teachers, and experts through the interfaces of u-learning systems.	• Emails • MSN or Skype use • Comments on the course, websites, etc.
Situation of instructional activity	In the u-learning environment, learning processes are embedded in daily life and knowledge requirements are presented within an authentic context.	• Linking to related learning materials • Students' feedback on learning materials
Context-awareness	U-learning environments are characterized by context-awareness, itself based on students' statuses or the capacity of an authentic environment to provide related information to students.	• RFIDs • GPSs • Sensors • Bio-feedback
Actively provides personalization	U-learning actively provides personalized supports to students, based on the student's particular context.	• Individualized learning database • User guidance
Self-regulated learning	U-learning systems provide functions that help students to actively control their learning progress by themselves.	• Calendars • Task-lists
Learning community	U-learning facilitates online community interactions by providing field experience via the Internet so as to enrich the learning interactions among community members.	• Blogs or forums • Messengers • Chat rooms
Adaptive learning	U-learning makes adjustment according to each learner's situation in order to be adaptable to each one's learning.	• Recommended system • Agent-based model
Constructivist learning	U-learning activities should be on the basis of learners' prior knowledge or experience and further extend to the learning of new knowledge.	• Testing System • Diagnostic System

In order to design and develop an evaluation method, it is crucial to first understand the characteristics of u-learning since u-learning is a learning method extended from e-learning and m-learning. Nevertheless, u-learning emphasizes that learners can learn ubiquitously and pervasively. Hwang et al. (2008) introduced the characteristics of u-learning, including context-awareness, initiative of knowledge acquisition, adaptive learning, and urgency of learning need. Chen and Li (2010) suggested that the environment of context-aware u-learning should support personalization and the situation of instructional activities. The context-aware u-learning also supports collaborative learning (Yang, 2006). Peng et al. (2008) argued that u-learning systems were interactive. Chen and Chung (2008) mentioned that u-learning environment could achieve constructive learning and self-regulated learning through learning activities. After conducting a survey of the literature, the various definitions of u-learning with their main characteristics and corresponding functions were categorized in Table 2. The corresponding functions were the tool models of the function emphasized by the u-learning characteristics. This study employs the ten characteristics of ubiquitous learning listed in Table 2 as the principal criteria for evaluating meaningful u-learning.

3. Design of the meaningful learning-based evaluation method for ubiquitous learning

This section discusses the three-phase design of a meaningful learning-based evaluation method for u-learning: (1) a model of a meaningful-based evaluation of u-learning; (2) procedures of the meaningful learning-based evaluation method for u-learning; and (3) the tools for the meaningful learning-based evaluation method.

3.1. A model of a meaningful learning-based evaluation of ubiquitous learning

Based on the rationale (described above) for a meaningful learning-based evaluation of u-learning, this study designs an evaluation model. The purpose of this model is to evaluate whether a u-learning environment achieves meaningful learning. The evaluation model involves characteristics drawn from both meaningful learning and from u-learning. Also, it adopts a hierarchical structure, similar to a top–down tree. The advantage of building such a hierarchical evaluation model (resembling a tree structure) is that it clearly depicts the

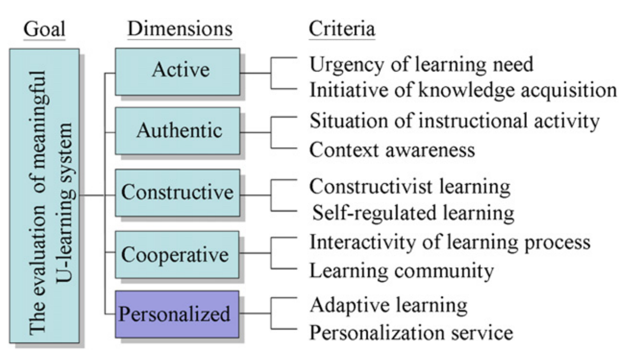

Fig. 1. A model of a meaningful learning-based evaluation of ubiquitous learning.

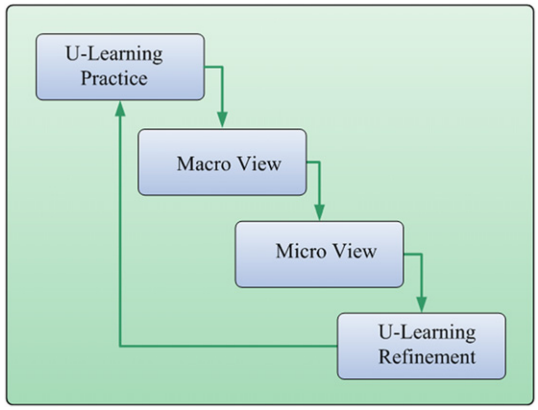

Fig. 2. The evaluation method framework.

relationships among goals, dimensions, and criteria (Saaty, 1990). By following this hierarchical structure, we attempt to develop an evaluation model for u-learning.

Next, we conduct a literature review to assess the degree of correspondence between the dimensions/criteria of meaningful learning and u-learning. The evaluation model we constructed has three levels: the first entails a goal, the second entails five dimensions, and the third entails ten criteria (see Fig. 1). At the goal level, a meaningful learning-based evaluation is used to evaluate u-learning activities. At the second level, meaningful learning is understood to entail the following dimensions: *active*, *authentic*, *constructive*, and *cooperative* (Grabe & Grabe, 2007; Jonassen, 1995; Karppinen, 2005). Furthermore, dimension about personalization was added since previous research on meaningful learning did not emphasize personalization. Meaningful learning was probably designed for the traditional education environment, namely classroom instruction, so personalized learning was less emphasized before. However, the features of personalization should not be ignored in e-learning, mobile learning, and u-learning nowadays (Chen, 2008; Chen & Chung, 2008; Chen, Lee, & Chen, 2005; El-Bishouty et al., 2007). In particular, u-learning emphasizes that learners can have personalized curriculums to learn more independently without time and spatial limitations. The third level highlights ten main characteristics of u-learning drawn from previous studies (Chen & Li, 2010; Hwang et al., 2008; Ogata et al., 2008; Peng et al., 2008; Yang, 2006). Essentially, these characteristics become the criteria linking the corresponding dimensions.

3.2. Procedures of the meaningful learning-based evaluation method for u-learning

The meaningful learning-based evaluation method for u-learning is comprised of the following four stages: (1) the u-learning practice, (2) a macro view, (3) a micro view, and (4) u-learning refinement (see Fig. 2). The method of evaluation is accomplished through a stage-by-stage process. Firstly, a learning activity is carried out within a u-learning environment. Secondly, participants in this u-learning activity are

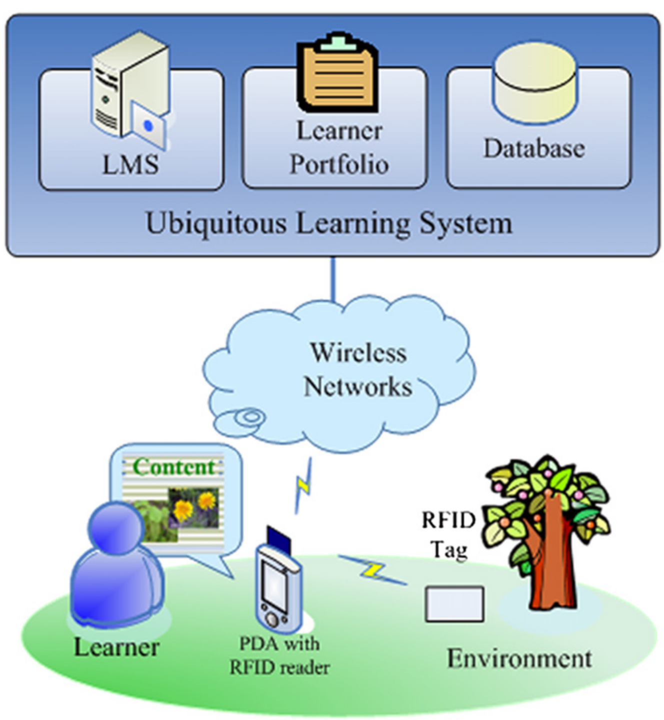

Fig. 3. The u-learning 1 structure.

Fig. 4. The system interface of u-learning 1: Content page (left) and quiz page (right).

asked to evaluate the u-learning itself by completing a meaningful learning questionnaire scale. In addition, at this stage we are able to analyze the entire group from a macro view, assessing the degree of meaningful learning that a developed u-learning environment can achieve (a macro view). In the subsequent micro view stage, we investigate still further the functions and characteristics of u-learning in order to develop a clearer understanding of its pros and cons with respect to meaningful learning. Finally, according to the results of these analyses, and by resolving the disadvantages that did surface, the u-learning environment could be adjusted or refined so that its quality is enhanced. Essentially, the refinement of the u-learning environment is assessed through real-world practice.

3.3. Instruments for the meaningful learning-based evaluation method

Instruments were developed in this study to evaluate whether u-learning can support students to achieve meaningful learning. One is implemented in the macro view stage, whereas the other is implemented in the micro view stage.

3.3.1. Instrument for the macro view

The purpose of the macro view is to evaluate whether u-learning environments and activities can provide learners with an opportunity to achieve meaningful learning. Next, to collect learners' opinions about u-learning environment and activities, we developed a questionnaire based on features of meaningful learning drawn from previous studies (Grabe & Grabe, 2007; Jonassen, 1995; Karppinen, 2005). The questionnaire contains the following five dimensions: *active*, *authentic*, *constructive*, *cooperative*, and *personalized*. Each dimension is represented by three items (themselves based on the definitions of the dimension). In addition, for validation purposes, two experts were invited to review and comment upon the items. The questionnaire contains a total of 15 items (see Appendix A). Each item is a statement about what a learner could do within a learning environment or with learning activities. A five-point Likert rating scale was used to measure the degree to which learners agreed with a given statement (from 1 = "very disagree" to 5 = "very agree").

3.3.2. Instrument for the micro view

In order to better understand both the feasibility of the u-learning environment as well as the students' learning activities themselves, a micro view was also implemented. Its purpose was to establish which characteristics/functions of a specific u-learning environment (and its activities) were most compatible with meaningful learning. At this stage, we could discern the pros and the cons of a u-learning activity according to a meaningful learning paradigm. As a result, the instructor and the developer could refine or adjust the u-learning activities accordingly.

Fig. 5. The u-learning 1: the ubiquitous tree-observing activity.

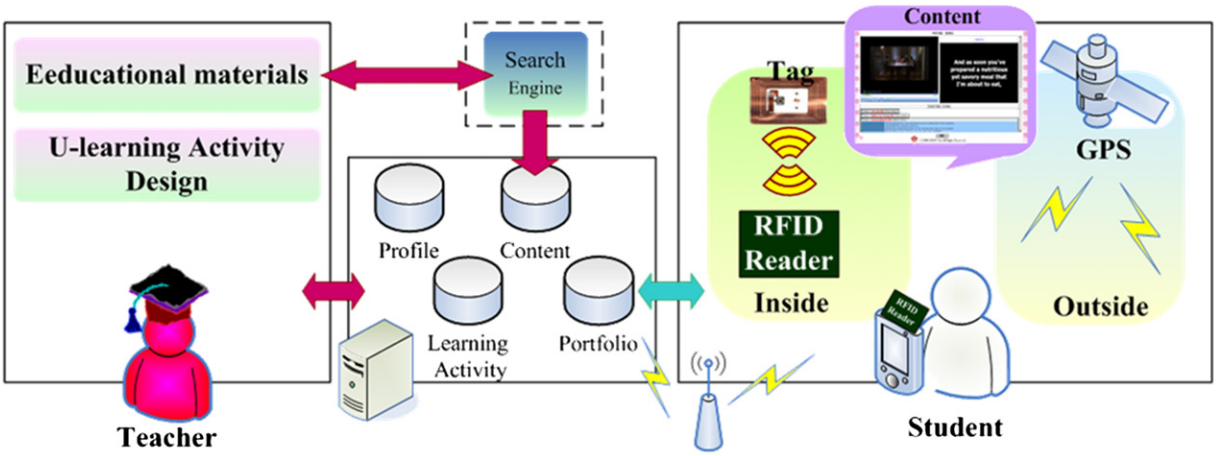

Fig. 6. The u-learning 2 structure.

The instrument for the micro view was based on Satay's (1990) analytic hierarchy process (AHP). Through a process of paired comparisons, the AHP questionnaire determines the pros and cons associated with multiform criteria (Pan, 2008; Sharma, Moon, & Bae, 2008). Hence, the AHP survey questionnaire was used for collecting learners' responses to questions about u-learning activities (see Appendix B). Ultimately, these results were used to define the characteristics of both meaningful learning and u-learning. To validate our findings, the items in the AHP questionnaire were constructed and verified by two educational technology experts. The returned AHP questionnaires were checked further using a consistency ratio (CR) to ensure their reliability. In general, a CR score less than 0.1 indicates consistency in judgments made by the participants (Saaty, 1990; Shee & Wang, 2008).

4. Implement of meaningful learning-based evaluation method for ubiquitous learning

To make this study more comprehensible, we conducted two case studies that illustrate how to apply our evaluation method to the real-world case studies: 1. the ubiquitous tree-observing activity and 2. the ubiquitous English learning system. To increase the feasibility of the method for evaluation, different u-learning systems were actually evaluated. In this study, two learning contexts for the u-learning systems were selected, respectively natural science and English. The case studies and evaluation results are elaborated as follows:

4.1. U-learning 1: the ubiquitous tree-observing activity

We have implemented the first u-learning system: a ubiquitous tree-observing activity. The u-learning system has three main components, a personal digital assistant (PDA), radio frequency identification (RFID) and learning management system (LMS). The PDA with RFID can detect a learner's context/environment and display related learning material immediately to a learner. The diagram (Fig. 3) presents the tree-observing u-learning environment, where an LMS is responsible for retrieving (from a backend database) materials

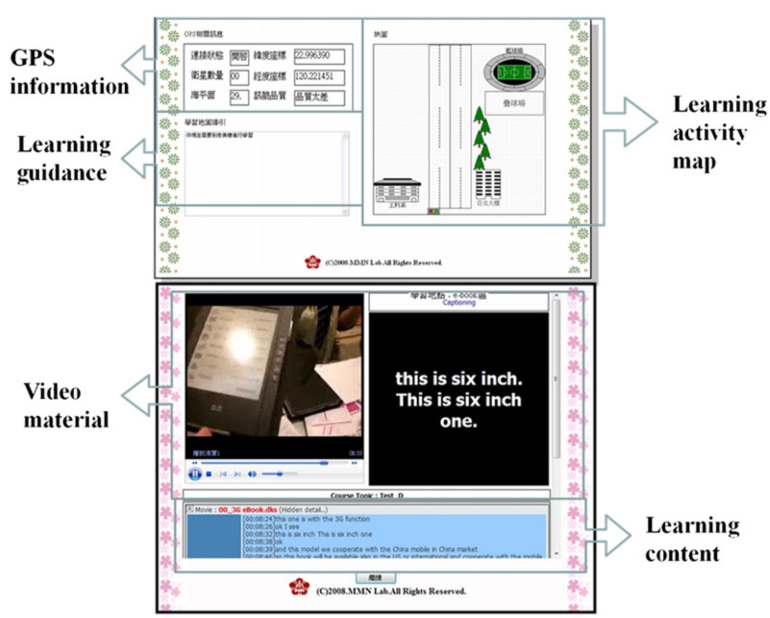

Fig. 7. The system interface of u-learning 2: Learning space guide (above) and learning material (below).

Fig. 8. The u-learning 2: the ubiquitous English learning activity.

necessary for any particular learning activity and for recording students' logs or Learner Portfolios. We attached RFID tags to trees, and assigned PDAs (with RFID reader) to learners. When the learners explored the environment using PDAs, the RFID tags would furnish the LMS with information about the learners' location. In light of this location data, the LMS could transmit tree-related content/problems (Fig. 4) to aid learners with learning tree-related concepts and to quiz the learners. Moreover, in response to being stimulated by a tree-related problem, a learner might attempt either to solve it collaboratively with peers or through field observations. Consequently, learners' impressions of the natural environment are likely to be deepened and tree-related knowledge is likely to be formed in their minds. The photograph below (Fig. 5) shows learners observing a tree.

4.2. U-learning 2: the ubiquitous English learning system

This study implemented the second u-learning system: the ubiquitous English learning system. Fig. 6 illustrates the system framework, which mainly consists of two parts, namely Teacher and Student. The Teacher includes the content of the teaching activities and materials designed by the teachers. At present, learning goals, sequences, objects, cues, etc. can be set in teaching activities. For teaching materials, movies and videos corresponding to teaching contexts are edited and selected through video search engines, and movie/video segments close to actual interactive scenarios are provided as proper English learning materials. In terms of the Student, the learning environments include indoor and outdoor environments. The GPS aware of outdoor contexts is suitable for the positioning of large targets. However, since signals could not be received in indoor environments, using only GPS will not cover all possible learning contexts. Thus, a learner's indoor position can be identified by portable devices, such as Tablet PC, combining with RFID devices, and contextual English learning content related to the position will be provided by remote servers through wireless network transmission. When learners are outdoor, they hold Tablet PCs with wireless network and GPS. GPS obtains longitude and latitude through satellite positioning, and information on relevant position will be obtained through the comparison between the system and the context awareness archive and then be sent to the learning management system. After that, the system will send appropriate English learning content back to the Tablet PCs or other mobile devices for the learners to have contextual English learning. The system is illustrated in Fig. 7 (above). Moreover, this system will show those materials suitable for the immediate context for learners, and the materials will be listed for learners to choose. English subtitle is also provided in the videos except of English videos and audios, and learners can also watch repeatedly the videos that they already watched to review the

Table 3
Result of macro view (u-learning 1).

Items		M	SD	r^*
Dimension 1: Active		3.94	0.61	
1.	ACT1	3.89	0.75	0.75
2.	ACT2	3.81	0.81	0.72
3.	ACT3	4.11	0.55	0.65
Dimension 2: Cooperative		2.85	0.64	
4.	COO1	3.21	0.69	0.72
5.	COO2	2.73	0.67	0.57
6.	COO3	2.61	0.71	0.61
Dimension 3: Authentic		4.09	0.62	
7.	AUT1	4.04	0.70	0.74
8.	AUT2	4.06	0.57	0.69
9.	AUT3	4.18	0.62	0.71
Dimension 4: Constructive		3.76	0.69	
10.	CON1	3.47	0.79	0.69
11.	CON2	3.78	0.69	0.63
12.	CON3	4.05	0.85	0.61
Dimension 5: Personalized		3.71	0.71	
13.	PER1	3.39	0.79	0.64
14.	PER2	3.68	0.69	0.57
15.	PER3	4.05	0.85	0.61

r^*: Corrected item–total correlation.

Table 4
Result of macro view (u-learning 2).

Items		M	SD	r*
Dimension 1: Active		4.16	0.78	
1.	ACT1	4.19	0.75	0.74
2.	ACT2	4.15	0.81	0.69
3.	ACT3	4.16	0.85	0.65
Dimension 2: Cooperative		4.01	0.77	
4.	COO1	4.11	0.89	0.79
5.	COO2	4.03	0.67	0.69
6.	COO3	3.91	0.71	0.65
Dimension 3: Authentic		4.06	0.75	
7.	AUT1	4.21	0.70	0.79
8.	AUT2	4.16	0.67	0.69
9.	AUT3	3.81	0.92	0.55
Dimension 4: Constructive		3.90	0.81	
10.	CON1	3.89	0.79	0.69
11.	CON2	3.78	0.79	0.67
12.	CON3	4.05	0.85	0.51
Dimension 5: Personalized		4.01	0.78	
13.	PER1	3.92	0.96	0.65
14.	PER2	4.03	0.76	0.61
15.	PER3	4.07	0.85	0.55

r*: Corrected item–total correlation.

English conversation, as indicated by Fig. 7 (below). Finally, Fig. 8 displays the photos taken in the learning activity of the ubiquitous English learning system.

4.3. *Evaluating u-learning*

The authors built two ubiquitous learning systems at an elementary school in southern Taiwan. The participants consisted of 32 fifth grade students, all of whom practiced two u-learning activities, from March to April 2011. Before commencing, we spent 1.5 h explaining and guiding the participants through the u-learning activity, including how to use all functions of the u-learning environment. After completing two u-learning activities, students were asked about their perceptions of it using our *macro view* instrument. Using a questionnaire (see Appendix A) a total of 32 students were surveyed about their satisfaction with two u-learning activities. The questionnaire used for the macro view consisted of 15 items; students were given 20 min to fill out the questionnaire.

Originally, the AHP-based questionnaire for the micro view was designed for those with sufficient knowledge in a field and who could easily understand the survey items (Saaty, 1990). However in this study, the AHP-based questionnaire was given to students (without such backgrounds), and hence, they required more detailed explanations for each item (Shee & Wang, 2008). As a result, the characteristics of ubiquitous learning needed to be clearly described and defined so that students could realize the intrinsic meanings of u-learning. After an intensive presentation on how to finish the questionnaire, a total of 32 students completed AHP-based survey questionnaire (see Appendix B), in about 30 min.

4.4. *Evaluation results*

The evaluation results are in three parts: the macro view, the micro view and u-learning refinement. Ultimately, our evaluation yields an overall understanding of the degree of meaningful learning inherent in u-learning. According to the results from the micro view, we see the positive and negative aspects (pros and cons) of the u-learning system's characteristics and functions. Finally, our findings help developers and instructors alike to improve and to refine their u-learning activities.

4.4.1. *Macro view*

Participants responded to the macro view questionnaire (see Appendix A) composed of Likert scales between values of 1 and 5 (from 1 which means "very disagree" to 5 which means "very agree"); these values indicated the degree to which participants agreed or disagreed with meaningful learning oriented statements that related to their perceptions of u-learning.

Concerning the means and standard deviations of the ubiquitous tree-observing activity (u-learning 1) were computed from the participants' responses to the items (see Table 3). Of the 15 items, 7 of them (items 3, 7, 8, 9, 12, and 15) had the highest means ($M > 4$), whereas 2 items (items 5 and 6) received relatively low means ($M < 3$). In addition, the order of the dimensions according to their means is *authentic* ($M = 4.09$), *active* ($M = 3.94$), *constructive* ($M = 3.76$), *personalized* ($M = 3.71$), and *cooperative* ($M = 2.85$).

Table 5
Correlation analysis of dimensions (u-learning 1).

Dimensions		2.	3.	4.	5.
1.	Active	0.54**	0.62**	0.64**	0.62**
2.	Cooperative		0.67**	0.59**	0.58**
3.	Authentic			0.61**	0.62**
4.	Constructive				0.61**
5.	Personalized				

** Correlations are significant at the $p < 0.01$ (two-tailed).

Table 6
Correlation analysis of dimensions (u-learning 2).

Dimensions		2.	3.	4.	5.
1.	Active	0.61**	0.58**	0.64**	0.67**
2.	Cooperative		0.56**	0.58**	0.54**
3.	Authentic			0.57**	0.59**
4.	Constructive				0.64**
5.	Personalized				

** Correlations are significant at the $p < 0.01$ (two-tailed).

Table 4 presented the means and standard deviations of the ubiquitous English learning system (u-learning 2). Of the 15 items, 10 of them (items 1, 2, 3, 4, 5, 7, 8, 12, 14, and 15) had the highest means ($M > 4$) In addition, the order of the dimensions according to their means is *active* ($M = 4.16$), *authentic* ($M = 4.06$), *cooperative* ($M = 4.01$), *personalized* ($M = 4.01$), and *constructive* ($M = 3.90$).

The Pearson correlation coefficients among the dimensions of macro view were presented in Table 5 and Table 6. The dimensions relationships indicated that many of the variables significantly. In other words, Table 5 and Table 6 presented that these five dimensions of macro view have high correlations with each other. These results indicate that these five dimensions could be investigated at the same time when evaluating the u-learning system.

4.4.2. Micro view

Data on the micro view were collected using the AHP questionnaire. Tables 7 and 8 show the weights of the different criteria and notes that all results obtained by the AHP pass a consistency test (a consistency ratio less than 0.1).

Following Table 7, these criteria of the ubiquitous tree-observing activity (u-learning 1) are presented in order of weights: *context awareness* (14.4%), *personalization service* (13.7%), *situation of instructional activity* (12.8%), *initiative of knowledge acquisition* (12.6%), *constructivist learning* (12.2%), *urgency of learning need* (8.4%), *adaptive learning* (7.7%), *interactivity of learning process* (6.4%), *self-regulated learning* (6.3%), and *learning community* (5.5%).

Table 8 shows these criteria of the ubiquitous English learning system (u-learning 2) in order of weights: *context awareness* (13.3%), *interactivity of learning process* (13.1%), *personalization service* (12.5%), *initiative of knowledge acquisition* (11.8%), *situation of instructional activity* (11.5%), *learning community* (9.2%), *adaptive learning* (8.6%), *urgency of learning need* (7.8%), *self-regulated learning* (7.7%), and *constructivist learning* (6.5%). Consequently, the results also show the relative advantages and disadvantages of the criteria employed in these case studies.

4.5. U-learning refinement

The result of the macro view displayed how much meaningful these evaluated u-learning systems could be in terms of learning. According to the u-learning systems' results of macro review in this study (see Figs. 3 and 4), the overall score of the dimensions of U-learning 2 was higher than that of U-learning 1. In U-learning 1's result of macro view, only "*authentic*" was satisfactory while "*active*", "*constructive*", and "*personalized*" were ordinary, and "*cooperative*" was even unsatisfactory. To increase U-learning 1's degree of meaningful learning, "*cooperative*" should be reviewed and improved. From the macro view questionnaire, it was found that Item 5- "I can share my experiences or knowledge with my peers" and Item 6- "My peers can share their experiences and knowledge with me" were the items with low scores. After the problem of u-learning 1 was initially understood, the result of micro view was further employed to discover insufficient criteria, respectively *learning community*, *self-regulated learning*, and *interactivity of learning process*. Hence, the insufficient criteria can be improved or new functions can be created to improve the quality of learning systems.

Finally, in light of results of the macro view and micro view, the advantages and disadvantages of these u-learning systems were then found. Therefore, the result of evaluation can be provided to u-learning system developers or teachers as the reference for system improvement or activity design to further improve the disadvantages, maintain advantages, and then enhance the benefit of u-learning systems.

5. Discussion and conclusions

This study designed and developed a meaningful learning-based evaluation method for u-learning. The evaluation method has several features. First, the evaluation has proven feasible and serviceable for the practice of u-learning. Second, the evaluation combines

Table 7
Result of micro view (u-learning 1).

#	Dimension	Criterion	Weight	CR
1	Active	Urgency of learning need	8.4%	0.02
2	Active	Initiative of knowledge acquisition	12.6%	0.01
3	Constructive	Constructivist learning	12.2%	0.01
4	Constructive	Self-regulated learning	6.3%	0.02
5	Authentic	Situation of instructional activity	12.8%	0.03
6	Authentic	Context awareness	14.4%	0.01
7	Cooperative	Interactivity of learning process	6.4%	0.01
8	Cooperative	Learning community	5.5%	0.02
9	Personalized	Adaptive learning	7.7%	0.01
10	Personalized	Personalization service	13.7%	0.03

Consistency ratio (CR): CR score less than 0.1 indicates consistency.

Table 8
Result of micro view (u-learning 2).

#	Dimension	Criterion	Weight	CR
1	Active	Urgency of learning need	7.8%	0.01
2	Active	Initiative of knowledge acquisition	11.8%	0.01
3	Constructive	Constructivist learning	6.5%	0.02
4	Constructive	Self-regulated learning	7.7%	0.02
5	Authentic	Situation of instructional activity	11.5%	0.01
6	Authentic	Context awareness	13.3%	0.01
7	Cooperative	Interactivity of learning process	13.1%	0.02
8	Cooperative	Learning community	9.2%	0.02
9	Personalized	Adaptive learning	8.6%	0.01
10	Personalized	Personalization service	12.5%	0.02

Consistency ratio (CR): CR score less than 0.1 indicates consistency.

characteristics of both meaningful learning and u-learning in an effort to make the u-learning activity more meaningful for students. Third, the principal evaluation data collected reflects the perceptions of students who had actually participated in the u-learning activity. Fourth, the evaluation was able to thoroughly evaluate u-learning from both a macro and a micro perspective. Fifth, we employed a cycle-based evaluation method. Such an approach offers a sound mechanism for improving the quality and sustainability of u-learning.

By objectively evaluating u-learning with respect to meaningful learning (Grabe & Grabe, 2007; Jonassen, 1995; Karppinen, 2005), this study indicates that the novel technologies employed were beneficial and meaningful for the learner. In particular, this study reveals characteristics common both to u-learning and to meaningful learning, upon which an appropriate evaluation method was then designed and developed. In addition, by implementing two case studies, we have both illustrated and proven the feasibility of such an evaluation. Using the results from this evaluation, u-learning developers and instructors can better understand the relative advantages and disadvantages of designing meaningful learning-based u-learning. Moreover, developers will be able to refine or improve inadequate designs, while taking advantage of superior ones.

In summary, the implementation of this evaluation method has presented some advantages as the following:

- The evaluation can accompany a u-learning activity without also introducing too much time and cost.
- The procedures involved in the evaluation method are of relatively short duration, explicit and can be performed quickly and easily.
- The evaluation method can reveal the advantages and disadvantages of both u-learning and meaningful learning characteristics.
- The evaluation method can provide suggestions for instructor and designer alike, so that they can adjust the u-learning and make it more adaptive.

Based on the results of this study, we recommend the following for future research. First, while the evaluation method has adopted the participants' perceptions of the evaluation data, one could nonetheless strengthen the evaluation method by incorporating other data sources (e.g., teachers' viewpoints or interviews). Second, future research could augment the proposed evaluation method so that it could accommodate emerging technologies applicable to education. Finally, u-learning is an innovative approach to learning, and because new technologies and new applications are continuously emerging, it too is still developing. Although this study finds that the current characteristics of u-learning environments match the requirements for meaningful learning, future studies must continue to examine the new functions and new applications associated with emerging u-learning environments, and if necessary, be prepared to develop new learning theories as well.

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Appendix A. The macro view questionnaire.

Dimension 1: Active
1. I can conduct learning on my own
2. I can monitor my own learning process
3. I can play an active role in the learning activity

Dimension 2: Cooperative
4. I can have learning related discussions with my peers in the learning activity
5. I can share my experiences or knowledge with my peers
6. My peers can share their experiences and knowledge with me

Dimension 3: Authentic
7. I can observe real learning objects
8. I can learn in an authentic environment
9. I can learn with authentic-environment related materials

Dimension 4: Constructive
10. I can link new ideas to my previous experiences
11. I can learn more efficiently in the learning environment
12. I can understand what to learn in the learning activities

Dimension 5: Personalized
13. I can plan my own learning progress
14. The u-learning system provides adaptive individual learning
15. The u-learning system provides personalization services

Appendix B. Example of the micro view questionnaire.

Criterion A	←A is more important than B								↔	B is more important than A→								Criterion B
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Urgency of learning need																		Initiative of knowledge acquisition

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