Interactive Learning Environments

ISSN: 1049-4820 (Print) 1744-5191 (Online) Journal homepage: http://www.tandfonline.com/loi/nile20

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To cite this article: Chia-Chen Chen & Pei-Hsuan Lin (2016) Development and evaluation of a context-aware ubiquitous learning environment for astronomy education, Interactive Learning Environments, 24:3, 644-661, DOI: 10.1080/10494820.2014.915417

To link to this article: https://doi.org/10.1080/10494820.2014.915417

Published online: 15 May 2014.

Interactive Learning Environments, 2016
Vol. 24, No. 3, 644–661, http://dx.doi.org/10.1080/10494820.2014.915417

Development and evaluation of a context-aware ubiquitous learning environment for astronomy education

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(*Received 26 January 2014; final version received 12 April 2014*)

In recent years information technology has been integrated into education to produce a series of trends, beginning with "electronic learning" (e-learning), through "mobile learning" (m-learning) and finally to "ubiquitous learning" (u-learning), which aims to improve learner motivation through overcoming the conventional limitations of time and location. U-learning practices are still being developed, and learners frequently experience difficulty focusing on learning objectives, and effective learning strategy tools are still lacking. This study reports the design of a context-aware astronomy learning system. The system integrates several technologies, including radio frequency identification, wireless communication networks, handheld mobile devices, and databases to help students learn astronomical concepts. Two content modules were developed in the context of natural science education for fifth-grade elementary school students in Taiwan. Indicators of user experience with the system were collected for further phenomenographic analysis, based on four perspectives of the Unified Theory of Acceptance and Use of Technology model to assess learner willingness to use this novel u-learning approach. Results show that ease-of-use and the availability of immediate operational or technical support are key factors in increasing learning motivation and performance.

Keywords: interactive learning environments; elementary education; ubiquitous learning; context-aware; phenomenographic analysis

1. Introduction

Internet-enabled mobile devices allow users to search and share information from any location at any time, and are gradually being used to supplement or substitute for conventional classroom instruction. Such "mobile learning" (or m-learning) practices provide learners with high mobility and convenience in that they are not obliged to stay at any particular location to engage in learning. However, m-learning activities are still largely contrived and inapplicable to situational learning. Thus, many experts have emphasized the importance of authentic learning activities because they can effectively improve learners' problem-solving skills (Herrington & Oliver, 2000; Hwang, Kuo, Yin, & Chuang, 2010; Lave, 1991). Authentic activities are carried out in a situational context, with learners situated in a designated place, and then interacting with learning objects through learning aids used in authentic

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learning activities. This new model is referred to as "ubiquitous learning" (u-learning), and is seen as a way to improve learner motivation and interest, allowing learning to take place in authentic contexts outside the classroom. The main features of u-learning are permanency, accessibility, immediacy, interactivity, situating of instructional activities, and adaptability (Li, Ogata, Hou, & Uosaki, 2013; Ogata, 2009). In practice, ubiquitous learning environments have been achieved through the use of wireless sensor networks, with devices that integrate high mobility with pervasive computing, such as smartphones, radio frequency identification (RFID) tags, and other mobile devices (Ogata et al., 2011).

To date, astronomical learning has primarily been conducted in a classroom setting, mainly consisting of lectures supplemented by multimedia displays, with knowledge acquisition assessed by written exams. In the classroom, students are easily distracted by peers or other influences. Instruction of astronomy can only occur through abstractions and models, which learners have trouble associating with real-world phenomena. Moreover, it is often difficult for learners to transition from classroom visual aids to the actual night sky, and learners sometimes have difficulty confirming compass readings in low light. These factors all contribute to a difficulty of developing a real sense of astronomical concepts or interest in the subject. However, a ubiquitous learning environment could potentially allow students to absorb astronomical knowledge while interacting with authentic environments, thus motivating learners to seek new knowledge autonomously. In the modified learning process, teachers serve not merely as lecturers but also as learning partners who collaborate with students to seek knowledge. Outdoor observation can be immediately followed by an examination to assess learning outcomes, and advanced questions can be provided to prompt further autonomous inquiry-based learning (Hung, Hwang, Lin, Wu, & Su, 2013). Through the proposed context-aware astronomy learning system (CAALS) students use Internet-enabled handheld mobile devices to experience and explore learning content which is specific to the learner's local time, location, and orientation in authentic environments, thus helping learners develop problem-solving skills and intrinsic motivation, and helps teachers track learner performance.

The development of u-learning environments has received only limited attention from education researchers (Tsai, Hwang, Chu, Lin, & Tsai, 2011; Tsai, Tsai, & Hwang, 2011). This study adapts existing technologies and learning theories to design an easy-to-use, learner-centered u-learning environment. The phenomenographic method, based on the Unified Theory of Acceptance and Use of Technology (UTAUT) model, is used to assess the willingness of students to engage in u-learning. Content modules were developed in line with the regular course curriculum, and the prototype system was tested by elementary school teachers and their students for use in astronomy classes. The main aims of the study are as follows:

- Establish a u-Learning system suitable for elementary school astronomy education
- Improve student interests and motivation in learning astronomy
- Assess student willingness to use CAALS

2. Relevant research

This study constructs a ubiquitous learning environment based on RFID technology, and then evaluates its impact on learning outcomes and attitudes. This section reviews the related literature. Section 2.1 describes RFID technology and its applications, Section 2.2 reviews key concepts in astronomy education, and Section 2.3 explains ubiquitous learning.

2.1. *RFID technology and its applications*

RFID consists of four components: readers, electronic tags, antennas, and an application system. The electronic tags can be categorized as active, semi-active, and passive depending on the configuration of their power source. Readers read collect and transmit data to and from the tags, and send the data to the application system for processing (Finkenzeller, 2003; Juels, 2006; Mazurek, 2009; Zhu, Mukhopadhyay, & Kurata, 2012).

RFID technology has been extensively integrated into instructional design in attempts to improve learning effectiveness, motivation, and interest. Wild Plant (1993) Ltd. integrated RFID technology into toys to help children learn the names and characteristics of various animals through observation, and to improve their power of observation. Koji, Mayumi, Masanori, and Fusako (2004) used computer-supported collaborative learning (CSCL) as a structure to develop the Musex system which combines an RFID reader and a personal digital assistant (PDA) to create collaborative learning environments in museum contexts. Tan, Tsung, and Chang (2007) used RFID technology to establish a ubiquitous learning environment in the Guandu Nature Park in New Taipei City, encouraging students to autonomously observe features of wetland ecology and to provide them with convenient independent access to a wide range of learning resources. Ogata, Yin, El-Bishouty, and Yano (2010) used PDA and RFID technologies to design the tag-added learning objects system for learning Japanese vocabulary, wherein students use an RFID reader to read RFID tags on certain objects, with related information and Japanese vocabulary and meaning displayed on the learner's handheld device. Wei, Hung, Lee, and Chen (2011) designed the Joyful Classroom Learning System on a theoretical foundation of experiential learning theory, constructive learning theory, and joyful learning to provide children with an engaging learning space through a Robot Learning Companion combining RFID technology. Tsai et al. (2011) created a ubiquitous learning platform for college students through combining PDA and RFID technologies. Chen and Huang (2012) used RFID technology to create a context-aware ubiquitous learning system to enhance learning intention in the context of a museum devoted to Taiwan aboriginal culture. Tang (2013) created a voice-driven learning platform for the blind called OntoBraille@RFID that used RFID to help users identify symbols and aids for the blind in real-world contexts for use in self-study. The back-end management system could then be used to monitor student learning progress.

2.2. *Astronomy learning*

In 1988, the International Astronomical Union formally proposed the concept of "Astronomy Learning". Percy (2000) suggested that the study of astronomy covers the cultural evolution of humanity, social history, philosophy, mythology, and religion, and also includes practical knowledge related to timekeeping, navigation, and climate studies. Therefore, astronomical education is very important, but is rarely covered in-depth in school curricula, providing only a rough introduction to basic astronomical concepts (Kesidou & Roseman, 2002; Plummer & Zahm, 2010). While astronomy courses are provided in elementary school and high school, the general public still has difficulty explaining relevant astronomical phenomena (Lelliott & Rollnick, 2010).

In Taiwan, school children are first exposed to astronomy in fifth-grade Science and Technology course work. According to the Ministry of Education (2003), the aim of the course is to "teach children how to conduct scientific exploration through observing, asking questions, planning, conducting experiments, inducing knowledge, judging information, and engaging in critical thinking." Fraknoi (1996) stressed that astronomical education should not be restricted to the classroom, but can be conducted through museums, planetariums, print and broadcast media, outdoor venues, and the internet. Wagner and Schmalstieg (2009) pointed out that textbooks cannot give students a sense of physical or practical experience, but that real understanding is derived from dynamic interaction with authentic contexts. Plummer and Small (2013) found high-school and college students had trouble explaining the workings of the solar system because their understanding of its mechanics was based on a one-dimensional description from textbooks and classroom demonstrations. This study seeks to establish a context-aware astronomy learning environment to allow children to learn astronomy in authentic contexts, and encourage them to pursue astronomical knowledge autonomously.

2.3. *Ubiquitous learning*

Ubiquitous learning allows learning to take place anytime and anywhere. Learning content is presented on mobile devices, and facilitates interaction between the learner and his/her learning environment, or two-way interaction with teachers or peers (Bekkestua, 2003). Many studies have established prototype ubiquitous learning environments. Chen, Kao, and Sheu (2003) developed a PDA-based bird-watching learning platform to support outdoor observational nature education, providing learners with a high degree of mobility and context-aware instructional support. Ogata and Yano (2004) used context-aware methods to develop the Language-learning Outside the Classroom with Handhelds platform which assists international students living in Japan to learn Japanese in the course of their daily lives. Chen, Kao, and Sheu (2005) established a butterfly-watching learning system, combining wireless networks, data mining technology, and PDA devices to allow students to engage in autonomous learning and knowledge extension. Hsi and Fait (2005) created the museum guide "eXspot" in which RFID induction technology is used to provide learners with context- and location-specific information based on their location and route through authentic learning contexts. Tan, et al. (2007) integrated RFID, wireless networks, and PDA devices to create an Environment of Ubiquitous Learning with Educational Resources, in which students learn about wetlands and conservation concepts. Huang, Huang, & Lin (2012) created a ubiquitous English vocabulary learning system to assist students in acquiring vocabulary knowledge through aids including video materials.

Ubiquitous learning environments are built based on situated learning theory. In a context-aware interactive learning process, learners acquire knowledge and skills, and then build rational and meaningful interpretations of knowledge (Brown, Collins, & Duguid, 1989). Many experts have pointed out that the effectiveness of real learning situations can be optimized by integrating situated learning theory into the teaching process (Luft, Roehrig, & Patterson, 2003; Mishra & Koehler, 2007; Smetana & bell, 2011). Effective learning should be implemented by solving problems and gaining knowledge through authentic experience, and cannot be achieved through drilling or memorization (Wang, Yu, & Wu, 2013). This study applies situated learning theory to the design of teaching processes and systems. Following an orientation session led by the teacher, students are allowed to wander outside under the night sky, turning the textbook contents originally provided unilaterally in classrooms into a two-way interactive learning process within an authentic context, giving students a stronger sense of astronomic concepts.

3. System design and architecture

This study was based on program development and system implementation, and the instructional content was adapted from the first chapter of the fifth-grade elementary school

Natural Science and Technology textbook. We first analyzed learning needs and course content, and then designed a new learning process and evaluated its feasibility. Learning tasks were designed to coincide with the appropriate season. Hardware components were tested in a laboratory environment to determine whether the device could be affected by environmental interference. The software component was developed in Microsoft Visual Basic 2010, using Microsoft SQL Server 2008 as the database platform. A context-aware learning environment was established in which students to use the RFID reader in their tablet PC to locate the cardinal directions using RFID tags previously placed at the scene. Proximity to certain RFID tags triggers specific learning materials on their tablet PCs, thus initiating the learning process. Immediately following the learning session, a two-tier adaptive test was administered, with correct answers leading to more difficult questions, and incorrect answers leading to appropriate learning materials for review.

3.1. *System architecture*

As shown in Figure 1, the students use a tablet PC with an RFID reader. The tablet PC connects to a database through a wireless network connection, logging student activity and calling contextually determined instructional content. The teacher can also monitor learner activity in real-time.

Once the learner's tablet PC reads a passive RFID tag, it connects to the database to call the data associated with the tab and display it on the screen. The database also records learner location, exam results, and profile.

Traditionally, learning takes place in indoor classrooms through textbook-based explanation. Teachers provide unilateral instructions and students can only absorb the materials transmitted to them through lectures and textbooks. The proposed system facilitates outdoor learning in several ways. First it replaces the conventional compass with RFID tags, thus

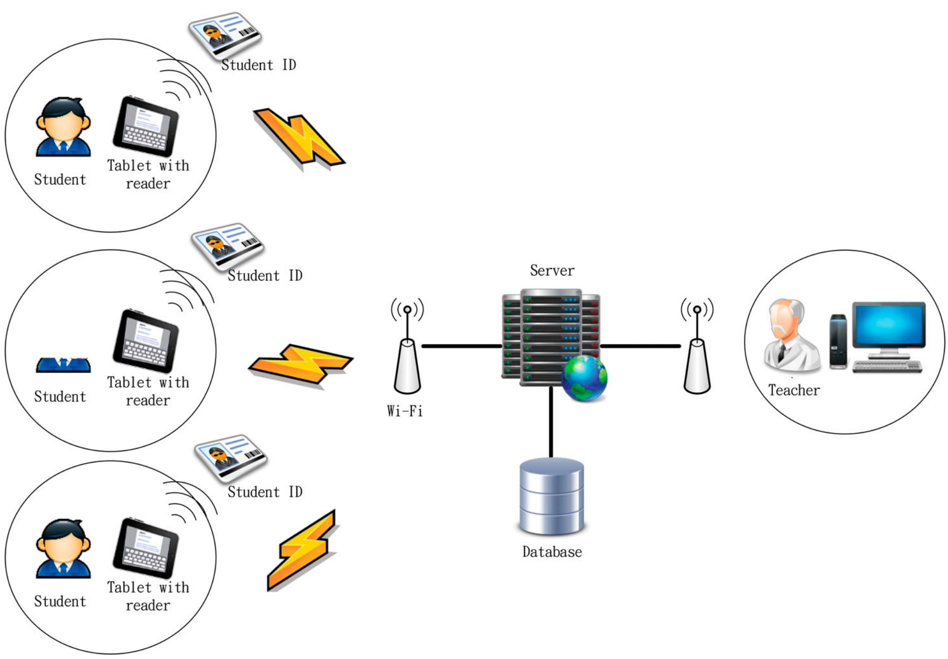

Figure 1. System architecture.

facilitating direction finding. The curriculum is season-specific, thus ensuring that the materials accurately reflect the night sky at the time. The tablet PC is lightweight and highly portable, thus allowing learners to access extensive supplementary information quickly and easily while engaged in real stargazing. This integration of real-world experience and personal observation with detailed, on-demand support acts to increase learner engagement and motivation.

3.2. *System functions*

The five major system functions are as follows

(1) Student functions

- Start star: free-form stargazing with constellations and star names superimposed on the screen.
- Mission: two content modules were produced for the prototype, each focused on a different constellation, and providing step-by-step instructions along with constellation-specific information.
- Exam: once students complete a mission, the system assesses learning outcomes through an adaptive test.
- Story: fairy tales associated with 88 constellations.
- Know-How: supplementary materials provide additional instruction in relevant skills.

(2) Teacher functions

- e-Portfolio: teachers can add, edit, delete, search, and monitor the profiles of individual students.
- Item Bank: teachers can add, edit, and delete exam questions.
- Account: teachers can monitor individual student progress.

3.3. *CAALS user interface*

Learners interact with the system through large, clear icons on the tablet PC touch screen. The interface is specifically designed to be clear and easy to use for elementary school students, as shown in Figure 2.

In the Start Star mode, the system displays the local sky superimposed with the star and constellation names, along with constellation outlines. The top left corner shows related information of the selected stars, such as magnitude, distance, and angle of elevation, as shown in Figure 3.

In the Mission function, the students are guided through finding specific stars, as shown in Figure 4.

After students complete their stargazing assignment, they take an exam as shown in Figure 5(a). The system automatically records students' performance in the database, and teachers can monitor grades and progress, provide supplementary activities or instruction, or adjust the course content, as shown in Figure 5(b).

4. Evaluation

A series of controlled experiments was performed on fifth-grade learners using CAALS. Once the learners had completed the learning activities, they were asked to complete a questionnaire to assess system effectiveness in improving learning motivation and effectiveness.

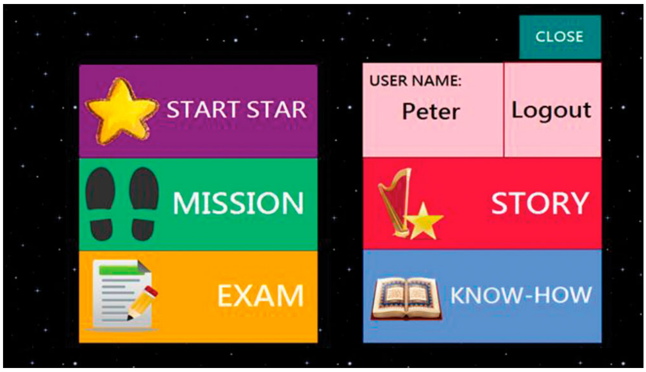

Figure 2. System start-up screen.

Figure 3. Stargazing screen.

4.1. *Experimental method*

- An experimental design suitable for non-equivalent groups was adopted, in which both an experimental group and a control group take a pre-test and post-test. The experimental group used CAALS, while the control group used traditional learning methods in the classroom. The control group students used an astrolabe and compass to search for the target constellations. The learning materials, exams, and questionnaire were all designed in collaboration with the participating teachers, thus ensuring that the teachers were fully able to lead the students through the activities. In this study, the Cronbach's α coefficient was used to assess internal consistency (Mehrens & Lehmann, 1987). Table 1 shows that the Cronbach's α value for all constructs had exceeded 0.7, indicating a high degree of reliability (Nunnally, 1978). Pre-test questions were based on students' prior knowledge and general astronomy concepts, including the Pole Star and the Great Diamond. The post-test mainly covered concepts taught in the learning activity and the constructs were identical to the pre-test questions, including the significance of the Pole Star and Great Diamond. A pair-sample *t*-test and an independent two-sample *t*-test were used to evaluate student learning performance of the experimental and control groups for comparison.

The questionnaire design adopted the UTAUT model to understand learner behavioral intention (BI) or willingness to use information technology. The model consists of four major dimensions including Performance Expectancy (PE) which is the extent to which the user believes the system will improve work performance, Effort Expectancy (EE), which is the user's perception of system ease of use, Social Influence (SI), which is the extent to which the user believes others will think he should or should not use this system, and Facilitating Conditions (FC), which is the extent to which the user believes

Figure 4. Big dipper mission.

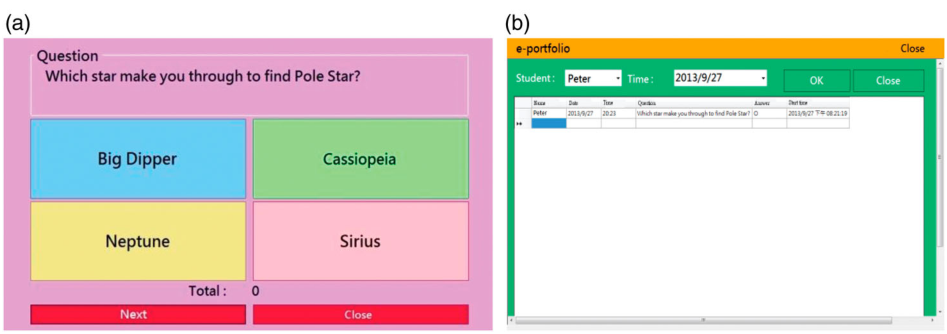

Figure 5. CAALS screenshots.

Table 1. Internal consistency reliability of the assessments and questionnaire ($n = 264$).

	Pre-test	Comprehension-test	Post-test	Questionnaire	
Cronbach's α	.83	.85	.88	PE	.898
				EE	.885
				SI	.866
				FC	.914
				BI	.955
				Total	.931

his/her current organization and technical infrastructure will support the use of the system (Venkatesh, Morris, Davis, & Davis, 2003). According to Venkatesh et al. (2003), the explanatory power of the structure on information technology usage is as high as 70% and is more effective than any other previous models. In this study, the four dimensions of UTAUT are used to explore students' willingness to use the astronomy instructional aid. A post-activity questionnaire was distributed to 132 students to assess the impact of performance expectations, EE, SI, and FC on intention to use the CAALS. The questionnaire used a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). A sample t-test was applied to determine intention to use, and to understand the student learning attitudes. The questionnaire was used to derive data on student attitudes toward learning and learning behavior in the context of the proposed u-learning platform. Each student was interviewed individually by trained researchers, with analysis and discussion of results conducted by phenomenography, a qualitative research approach mainly used to understand cognition and learning (Marton, 1981, 1986, 1994; Lin & Tsai, 2008). Many researchers prefer to use phenomenography to explore subjective learner concepts about how learning is accomplished (Richardson, 1999). This study follows the UTAUT model, using the questionnaire and classification method introduced by Lin and Tsai (2008) and Tsai et al. (2011). To better understand student acceptance of the proposed system, their responses are plotted in a dendrogram, which can clearly show the different thoughts students have regarding the system and the relationship between each dimension. This approach helps determine the distribution and commonality of the student opinions on learning (Lin & Tsai, 2008). Past studies have shown that the learning method and learning outcome are closely related to how students think about learning (Burnett, Pillay, & Dart, 2003; Chin & brown, 2000; Hofer & Pintrich, 1997).

4.2. *Participants and learning activity design*

The teaching materials, focus, and methods are based on the Astronomy learning unit of the fifth-grade Natural Science and Technology textbook, and were designed in consultation with experts and teachers. The aim of the proposed system is to encourage and enable learners to gain a deeper understanding of the course content than might otherwise occur through conventional classroom instruction and memorization. The process of observation can enhance or stimulate student interest in learning. Active stargazing and knowing the names of the constellations help students identify objects in the sky, and familiarity with the mythology behind the constellations enhances learner interest in stargazing.

A total of 264 participants (145 male, 119 female) fifth-grade students were recruited from 8 elementary schools in northern Taiwan. In this research, they were randomly split into experimental and control groups. Content for the prototype consisted of two modules, respectively, focused on the Pole Star and the Great Diamond. The lessons include observation and comparison exercises in which the students compare the sky shown on the tablet PC with the real sky to find specific stars.

Figure 6 shows the research chronology. In Phase 1, the experimental group and control group both engaged in textbook-based learning activities in the classroom. The pre-test was designed to assess the relevant knowledge of both groups prior to the learning exercise. Some terms and semantics were amended to better match the subject. During the two weeks following the pre-test, teachers used conventional teaching methods to introduce basic astronomy concepts including stellar position change, the astral encyclopedia, the night sky in the various seasons, and constellation-related mythology. The course of instruction was followed by a comprehension and recall test mainly based on basic knowledge of astronomical constellations.

In Phase 2, the students in the experimental group were taken outdoors at night to use the proposed CAALS system with the two content modules previously described. The control group used astrolabes and compasses to observe astronomical constellations outdoors at night. The activity stage took approximately 120 minutes for each group. In the activity, the control group attempted to locate the target stars using the astrolabe and compass, while the experimental group did the same using the CAALS. In the Pole Star learning unit, students searched for the Big Dipper, Cassiopeia, Neptune, and Sirius, while the Great Diamond learning unit had learners search for Arcturus and Spica. The learning scenario is illustrated in Figure 7.

In Phase 3, the two groups returned to the classroom to complete a post-test (30 minutes), with the experimental group answering an additional post-test questionnaire (15 minutes). The post-test mainly tested students on their understanding of basic astronomical concepts (e.g. change in stellar position) and their knowledge of the constellations. The questionnaire was administered based on the UTAUT model to assess factors affecting student willingness to use the system.

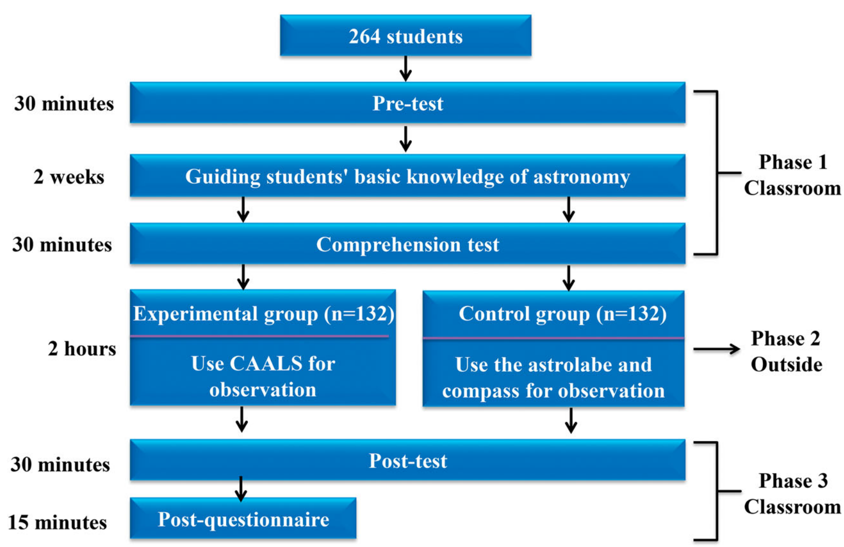

Figure 6. Research chronology.

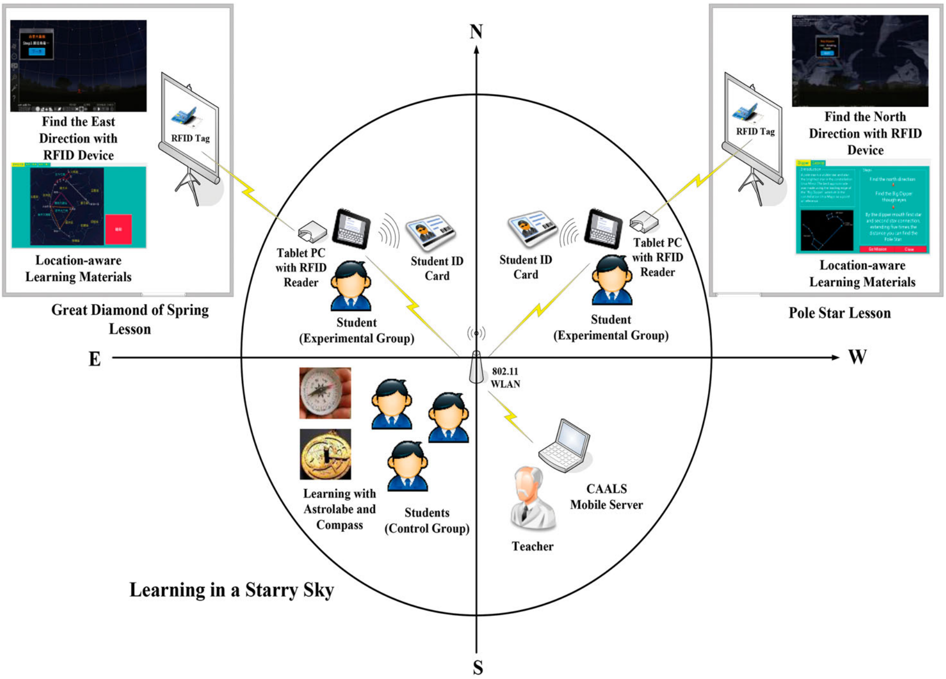

Figure 7. Learning scenario.

4.3. *Data analysis and discussion*

Table 2 shows the mean grades and standard deviations of the evaluations for each learning activity. The average pre-test score in the experimental group was 47.21 ± 4.86 points, while that of the control group was 48.78 ± 4.75 points. Thus, both groups had similar levels of understanding of astronomical concepts prior to the activity. Results were similar for the comprehension test (62.92 ± 4.76 vs. 63.63 ± 4.54). The results indicated that traditional classroom learning and textbooks are adequate to properly instruct students in astronomical concepts.

Table 3 compares the pair-sample t-test results for the evaluations of the experimental group and control group. The t-test for the experimental group between the pre-test and comprehension test ($t = -17.098$, $p = 0.000$) and between the comprehension test and post-test ($t = -17.930$, $p = 0.000$) was both significant, indicating that the learning performance of the experimental group has improved. It also indicates that learning performance knowledge acquisition and retention improved over time. The t-test results for the control group between the pre-test and comprehension test ($t = -26.062$, $p = 0.000$) and between the comprehension test and post-test ($t = -12.767$, $p = 0.000$) were both significant, indicating that the learning performance of the control group was different. The

Table 2. Mean grades and standard deviations of evaluations for each learning activity.

	Pre-test	Comprehension test	Post-test
Experimental group	47.21 ± 4.86	62.92 ± 4.76	83.53 ± 5.52
Control group	48.78 ± 4.75	63.63 ± 4.54	72.75 ± 4.30

Table 3. Pair-sample *t*-test results.

	Pre-test with Comprehension test	Comprehension test with Post-test
Experimental group		
t	−17.098	−17.930
p	0.000*	0.000*
Control group		
t	−26.062	−12.767
p	0.000*	0.000*

$^*p < .01$.

Table 4. Two-sample *t*-test results.

	Pre-test	Comprehension test	Post-test
t	0.256	0.657	15.960
p	0.799	0.514	0.000*
Cohen's *d*	0.326	0.152	2.178
Hedges's	0.324	0.151	2.166

* $p < .01$.

results for these two groups indicate that outdoor teaching is useful and helpful for students learning astronomical concepts.

Table 4 shows the *t*-test results for each learning activity. "Effect size" is used to measure significant differences between evaluation results of the two groups. Cohen (1992) pointed out that the effect size under .20 indicates a small effect, .50 indicates a medium effect, and greater than .80 indicates a large effect, and these indicators can be used to compare the baseline experiment results for the two groups. If the size effect is irrelevant (i.e. less than 0.5), it suggests that the initial conditions for the two groups are similar. Thus, the learning performance of the two groups was significantly different if the effect size is greater than 0.8. We also used Hedges's to assess and evaluate the appropriate effect size given its advantages in handling sample size problems (Hedges & Olkin, 1985). The values 0.2, 0.5, and 0.8 respectively, represent a small, medium, and large effect size.

Both groups took both the pre-test and comprehension test prior to the outdoor experiment. As shown in Table 4, for both groups the *t*-test results for the pre-test ($t = 0.256$, $p = 0.799$, $d = 0.326$, =0.324) and the comprehension test ($t = 0.657$, $p = 0.514$, $d = 0.152$, =0.151) were not significant, indicating that the initial conditions for both groups were similar, that both groups of students lacked an understanding of astronomical concepts, and that such an understanding is difficult to achieve through conventional classroom instruction.

As shown in Table 4, the *t*-test results for both groups for the post-test ($t = 15.960$, $p = 0.000$, $d = 2.178$, =2.166) were significant, suggesting dissimilar initial conditions between the two groups. In addition, as shown in Table 2, the average post-test score of the experimental group (83.53 ± 5.52) exceeded that of the control group (72.75 ± 4.30) by nearly 11 points, indicating that the proposed CAALS improved learning performance.

4.4. *UTAUT perspectives of u-learning*

This study follows UTAUT conventions proposed by Lin and Tsai (2008) and Tsai et al. (2011) for implementing questionnaires. The phenomenographic method can be used to clearly show the different opinions students have toward the proposed system and the relationship between each perspective, making it useful for determining the distribution and commonality of student ideas on learning. All student feedback is organized in a tree diagram in Figure 8, clearly illustrating students' various conceptions of u-learning, and elaborating the relationships among these conceptions with the UTAUT model. Agreement with a questionnaire item is signified by 4 (*agree*) or 5 (*strongly agree*). In addition, if the respondent agrees with all perspectives, we take this as an indication that the learner is strongly favorable to adopting the CAALS. The questionnaire is given in Table 5.

A "tree of UTAUT perspectives of u-learning" was used to represent the multiple conceptions of each student toward CAALS. The tree is drawn according to the frequency with which students indicated agreement with a particular questionnaire item. The tree root expresses the maximum frequency of the various conceptions expressed by the students regarding the u-learning system. As shown in Figure 8, the "performance expectancy" (PE) perspective is the root, as all interviewed students expressed this view. Figure 8 also shows that only four students "PE(4)" selected this perspective as a single understanding without interference from other perspectives. Next, the first-tier branch indicates mixed understandings across different perspectives. In this study, the "performance expectancy" perspective overlaps those of "social influence", "effort expectancy", "facilitating conditions", and "behavioral intention". For example, six students simultaneously held the "effort expectancy" perspective and the "performance expectancy" perspective, and are indicated as "EE(6)" in the tree. Similarly, in the second- and third-tier branches, the results indicate the best commonalities of the combinations across different perspectives on u-learning. For example, 50 students had mixed understandings (among PE, EE, SI, FC, and BI) and willingness to use CAALS, and only 2 students expressed willingness to use across PE, EE, SI, and BI. As these two students shared the foundation PE–EE–SI, they were mapped into a main branch.

Four important findings were derived from the tree structure. First, 97% (128 of 132) of the students marked the PE perspectives as significant, indicating that students were willing to use the CAALS system, which reflects the findings of Chen and Huang (2012) and Ho,

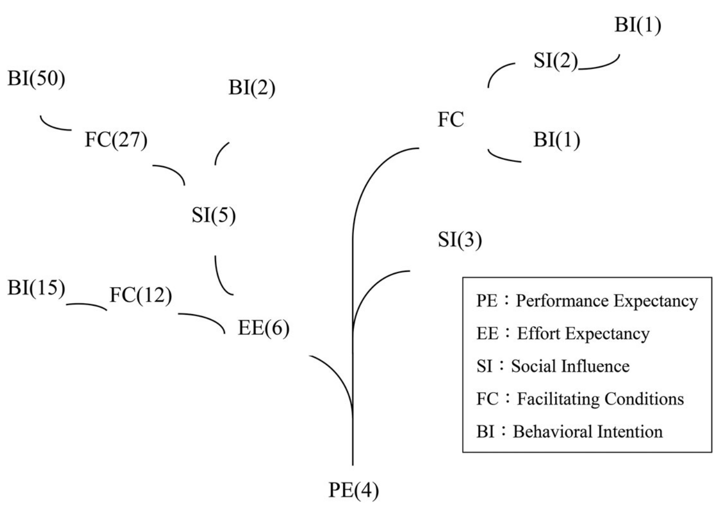

Figure 8. Tree of UTAUT perspectives of u-learning.

Table 5. Questionnaire items.

Perspective	Item
PE	CAALS helps me to quickly complete the learning content
	CAALS helps improve my knowledge of astronomy
	CAALS helps me learn
EE	I think CAALS is very simple to operate
	I think CAALS is easy to use
	I can properly operate CAALS
SI	Classmates who influence my behavior think I should use CAALS
	Classmates who are important to me think I should use CAALS
	I will use CAALS because many other classmates are using and recommending it
FC	I have the knowledge necessary to use CAALS
	Teacher will help me learn to use CAALS
	I am very supportive of teachers using this system
BI	I am willing to use u-learning systems in the future
	I will continue to use u-learning systems with RFID-enabled devices
	I will use new u-learning features in the future

Hung, and Chen (2013) that perceived usefulness is the key factor in determining user willingness to use a new system.

Second, 69 students marked the BI perspective as significant and 67 of these respondents also marked the EE perspective as significant, indicating that convenience and ease of use will increase willingness to use the system, which is consistent with findings from Chen and Huang (2012) and Ho et al. (2013).

Third, among the students who marked BI with both PE and EE, 15 students marked the FC perspective as significant while only 2 students marked the SI perspective as significant. This suggests that when using the new system, students need support and assistance from teachers and others, and access to immediate instruction and assistance will increase students' willingness to use. This finding is consistent with that of Teo (2011) that adequate support will increase willingness to use.

Finally, the tree clearly shows that SI does not significantly affect BI. The students who made up the sample in this study can acquire knowledge through many channels, including books or other learning aids, thus the SI perspective does not significantly affect BI. This finding corresponds with that of Chen (2011) in that SI has no significant effect on BI without mandatory usage or if users have experience in computer multimedia. Teo (2011) pointed out that the impact of SI on teachers' intention to use new technology is not significant. Many teachers do not rely on information technology in the classroom, and what technology has been introduced in classrooms was usually done so at the suggestion of the principal or department heads (Chen, Chang, Chen, Huang, & Chen, 2012). Ho et al. (2013) believed that SI is a key factor in determining BI, in that family members, friends, and teachers easily affect user decisions regarding the use of new systems. However, our results seem to indicate otherwise. Given that the new system is mandatory for schools, the intention to use is relatively high.

This study suggests that the key factors affecting willingness to use the system are effectiveness in improving learning outcomes and ease of use. Learning systems should provide a classroom version, as this will impress upon students that the system is an effective learning tool rather than just a learning aid. Teachers should also be familiar with the system and have a positive attitude toward it, thus ensuring that they will be willing to guide their students in its usage.

5. Conclusion

The proposed CAALS provides learners with easy access to real-time instruction in basic concepts in astronomy, and is used to help young learners identify stars and constellations while engaging in outdoor stargazing. Assessments found that system usage significantly improves knowledge acquisition and retention, and the proposed platform can serve as a reference for the future development of such learning aids for other courses. Venkatesh et al.'s (2003) UTAUT model was used to explore the willingness of students to use the proposed system. Four important findings were derived from the phenomenographic analysis. First, willingness was found to be primarily dependent on perceived usefulness. Second, ease of use had a significant impact on the users' willingness to use the new information system. Third, users would be willing to adopt the new information system given the immediate availability of operational or technical support. Finally, willingness to use new technologies or information systems could be additionally improved by recommendations from peers and teachers.

The present research is subject to several limitations. First, the content of the prototype was limited to astronomy, and future content modules can be developed to include a wider range of subjects. In addition, future longitudinal studies would be helpful to track improvements in learning outcomes over time. Future work will also analyze learner study logs for ways to improve system usability.

Acknowledgements

The authors thank the support of National Scientific Council (NSC) of the Republic of China (ROC) to this work under Grant No. NSC101-2410-H-005-068 and NSC 101-2622-E-005-016-CC3. The authors would like to thank Professor Chin-Shan Wu for his constructive suggestions for questionnaire design. In addition, the authors also gratefully acknowledge the Editor and anonymous reviewers for their valuable comments and constructive suggestions.

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