Ubiquitous learning website: Scaffold learners by mobile devices with information-aware techniques

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Abstract

The portability and immediate communication properties of mobile devices influence the learning processes in interacting with peers, accessing resources and transferring data. For example, the short message and browsing functions in a cell phone provide users with timely and adaptive information access. Although many studies of mobile learning indicate the pedagogical potential of mobile devices, the screen size, computational power, battery capacity, input interfaces, and network bandwidth are too restricted to develop acceptable functionality for the entire learning processes in a handheld device. Therefore, mobile devices can be adopted to fill the gap between Web-based learning and ubiquitous mobile learning. This study first creates a website, providing functions enabling learning to take place anytime and anywhere with any available learning device, for ubiquitous learning according to various properties of mobile devices. Nowadays, learners' behaviors on a website can be recorded as learning portfolios and analyzed for behavioral diagnosis or instructional planning. A student model is then built according to the analytical results of learning portfolios and a concept map of the learning domain. Based on the student model and learners' available learning devices, three modules are developed to build a ubiquitous learning environment to enhance learning performance via learning status awareness, schedule reminders and mentor recommendation. Finally, an experiment is conducted with 54 college students after implementation of the ubiquitous learning website. Experimental results indicate that the proposed system can enhance three learning performance indicators, namely academic performance, task accomplishment rates, and learning goals achievement rates.
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1. Introduction

Mobile devices can facilitate human interaction and access to information resources anytime and anywhere. Mobile devices, such as cell phones and personal digital assistants (PDAs), are widely used in daily life for various purposes. Many mobile applications to help commercial services have also been developed for mobile

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devices. These devices can be adopted to access Internet resources without time or place constraints. Applications in mobile devices can facilitate learning very well with proper design. However, mobile devices for learning are limited by screen size, computational power, battery capacity, input interface and network bandwidth. Mobile device applications must occasionally connect to a remote server to increase the efficiency and usability of a function.

Many mobile applications have been developed to aid working, traveling, tour guiding and learning. According to Mari (2000), the purpose of many mobile applications is to obtain context-aware information for personal help. For instance, Want, Hopper, Falcao, and Gibbons (1992) developed an active badge location system as an office tool to help locate a member's location by IR sensor. The telephone receptionist could find out a person's location, and direct the call to appropriate phone. Want's research group also presented a ParcTab system, i.e., a palm-sized computer with wireless functionality. Each office room had a transceiver to find the user's location in the office, and the system would find the most convenient local resource for use with the device. Several researchers have also applied the wireless communication and mobile computing devices to improve field learning or group collaboration. For example, Roy Pea studied how wireless handheld devices can be adopted to improve networks efficiency, aggregate coherently across all students, and help conduct a class (Roschelle & Pea, 2002). Additionally, the use of mobile devices in the field for scientific data collection, nature observation and data analysis has been investigated (Rieger & Gay, 1997; Soloway et al., 1999; Staudt & Hsi, 1999). Moreover, experience of mobile learning in field study indicates requirements of ubiquitous learning concepts and applications (Chang, Sheu, & Chan, 2003). A ubiquitous learning environment allows students to learn with a PDA, WebPad, Tablet PC or laptop, in indoor, outdoor, individual, and group situations.

Although those studies indicate significant support for mobile learning, few researchers have discussed ways of integrating mobile devices with web-based learning systems to cover most learning processes by generating a ubiquitous learning environment. Although Mark Weiser, the forerunner of ubiquitous computing, showed that the development of ubiquitous computing is not very mature, he has stated that human–computer interaction would be more natural in a ubiquitous computing environment than in current computer environments (Weiser, 1993). From the reality perspective, building a ubiquitous learning environment requires a "ubiquitous" learning device accessible by every learner all times. Consequently, a cell phone is the only candidate among various mobile devices, such as a PDA, tablet PC or laptop.

The analysis of content in 388 SMS (short message service) messages for a mobile learning experiment over five weeks shows that SMS messages are helpful for activities relating to information, supervision and feedback (Seppälä & Alamäki, 2003). Another framework for context-aware computing categorizes activities as information, communication and creation (Anhalt et al., 2001). Furthermore, "context discovery" is one of the main features of a general mobile learning architecture (Trifonova & Ronchetti, 2004). Hence, this study integrates those frameworks from the perspective of learning context awareness as information awareness, schedule awareness (supervising + communication), and interaction awareness (feedback + creation). In other words, the proposed ubiquitous learning environment scaffolds learners via activities for information perception, scheduling and interaction.

The theoretical framework for the study mainly refers to activity–attention framework proposed by Anhalt et al. (2001). In that framework, the *Distraction Matrix* is proposed to discuss the spatial and temporal aspects of context-awareness applications because most context-aware applications fall into two categories of location-based and schedule-based services. Although context awareness, which is a term from computer science, indicates for devices to have information about the circumstances under which they operate and can react accordingly, this study transforms context into specified learning circumstances. Hence, a learner can know why he/she should be doing a learning task, what a learning community is doing, when a learning task should be done, and where a learning partner could be found. However, the two dimensions of Distraction Matrix are not enough to represent issues in a learning context-awareness application. Hence, the third dimension of learning status awareness is added to accomplish the theoretical framework. Furthermore, we should design some meaningful activities for each dimension as exemplars to demonstrate how to take the advantages of learning context awareness under a ubiquitous computing environment.

To construct a ubiquitous learning environment, three representative modules, representing each activity, were developed to promote awareness of learning contexts by integrating a cell phone and learning website.

Table 1
Relationships among assumptions of performance indicators, awareness techniques and solutions

Learning performance indicator	Learning context awareness	Ubiquitous learning solution
Academic performance	Information awareness for grade aware	Learning status awareness
Task accomplishment rates	Schedule awareness for agenda aware	Schedule reminder
Learning goals achievement rates	Interaction awareness for peer–tutor aware	Mentor arrangement

The first module, called *Learning Status Awareness*, considers a cell phone as an instant message transceiver affecting students' learning behaviors. The analytical results of the student model indicate that proper instructions and notifications can be transmitted to students by SMS communication. The cell phone with WAP (Wireless Application Protocol) functionality allows students to interact instantaneously with the system. The second module, called *Schedule Reminder*, enables learners to remain aware of a teacher's instructional plans and their own learning schedule. The third module, called *Mentor Arrangement*, acts as a mediator in peer consultation and discussion through cell phone communication. In summary, the three modules can keep learners on task when they only have a cell phone available for interaction with the learning website.

To create the ubiquitous learning environment, this study presented a system enabling students to learn by a Desktop PC, laptop, PDA or cell phone. Students can undertake online learning by using any one of these learning devices to interact with the Web-based learning system. Based on the student model, the information notification mechanism transmits instant learning material to learners to increase their awareness of learning contexts. Students can immediately interact with the learning system with just-in-hand learning devices and perform relevant learning activities. Wireless communication can thus bridge students, teachers and the web-based learning system. Hence, a teacher can send instant messages to students to influence their learning. Students can immediately follow these instructions to undertake learning activities on various learning devices. Students can use the ubiquitous learning website to access resources and improve their learning outcomes. The system can also recommend peer mentors for students, who can consult with them via voice communication.

Table 1 shows the research assumptions based on the theoretical framework of this study. The first column lists selected learning performance indicators to be measured. The second column explains the reasons for every indicator to promote learning context awareness. The third column shows the developed modules for every useful SMS-based learning activity on the ubiquitous learning website. After these modules were implemented, an experiment was conducted to determine their effect on learning performance indicators. This work is organized as follows. The introduction is followed by a system overview section, which includes subsections describing the architecture for each module. The experimental results of the three modules are then presented. Finally, conclusions are drawn.

2. System overview

Fig. 1 illustrates the scenario and conceptual design of the ubiquitous learning environment. The conceptual design includes device adaptive and user model adaptive components, which are described in the following sections. Briefly, the scenario shows that students can learn using Desktop PCs, laptops, PDAs and cell phones in the ubiquitous learning environment. Students' learning behaviors through any learning device are recorded to tune the "default" student model in the learning website. Notifications and adaptive learning support messages are sent to learners by SMS. Students can then use the mobile learning devices or available computers to perform learning tasks immediately. Moreover, the learning system can recommend mentors that questioners can consult using a cell phone according to the constructed student model. Because students may use different devices when they are in different places, the learning system should support the presentation of learning materials and interaction with learners through all devices. This system fulfills the "ubiquitous" learning environment since students can receive instructions, notifications and recommendations on their cell phones. Students can connect to the learning system later to browse or interact using portable devices or desktop computers.

To support students in learning with PDA and cell phone, two additional specific views for PDA and cell phone are generated to present the content and information in the device adaptive component. While using a desktop PC or a laptop, students can use all the functions provided by the web-based learning system. Only
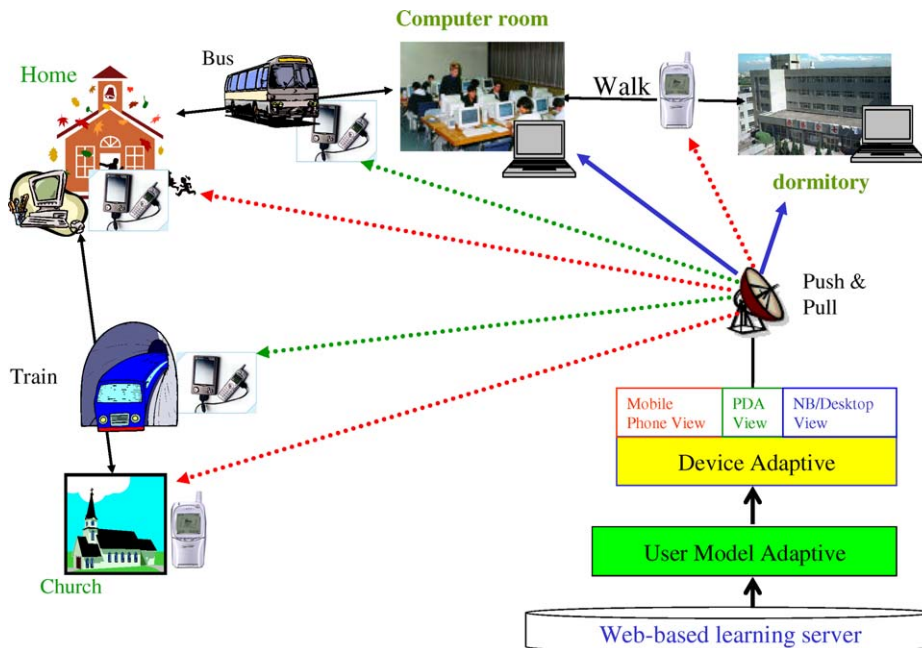
Fig. 1. Scenario and conceptual design of the ubiquitous learning system.

limited functionality is provided in mobile learning devices due to their limited computing power. Students can learn anywhere and at their own pace on any suitable learning device. The device adaptive component can record learners' behaviors and test results in various mobile learning devices, enabling the user model adaptive component to generate the student model to provide adaptive support for learning.

The user model adaptive component determines "what" and "when" to deliver proper learning materials, such as announcements and reminders, to learners' devices through the device adaptive component. For example, the user model adaptive component transmits an assignment reminder to students' cell phones in SMS message format according tasks in personalized schedules. To send the appropriate learning materials based on a student's learning status, a "default" student model is initially built for the user model adaptive component to prepare appropriate learning material and information, derived from the schedule and learning goals in the instructor's syllabus, to promote student learning and provide adaptive mobile learning support. However, the "default" student model may not be suitable to every learner. Hence, the system allows the "default" student model to be tuned to a specific student model according to a learner's online learning records.

Notably, this study adopts the extended definition of student model that can represent awareness of learning status. The conventional definition of the student model represents performance in the domain, acquisition order of the target knowledge, analogy and learning strategies, while the extended definition also represents awareness and reflection (Bull, Brna, & Pain, 1995). This work focuses on constructing the awareness component of a student model. Moreover, a student's online learning portfolio can be analyzed to identify what should be provided as appropriate learning support (Chang, Chen, & Ou, 1998). Consequently, to provide students with adequate scaffolds at the appropriate time, this component considers course progress, students' current learning status, students' learning goals and assigned learning tasks.

Based on the conceptual design in Fig. 1, three modules are presented as follows:

1. *Learning status awareness module*. This module analyzes students' online learning performance, such as learning works, test results and self-assessment results, to capture a learner's knowledge acquisition status. The module transmits messages about unfamiliar concepts to remind students of what they should learn in a given time frame. The module can also provide adaptive pop-up quizzes on a cell phone to increase learners' learning opportunities.

2. *Schedule reminder module*. This module enables teachers to manage and adjust the course schedule. All the adjustments from a teacher are immediately applied to students' personal schedules in the web learning system, and students must adjust their personal learning schedules accordingly. Students are reminded of incoming tasks and urged to complete them. Additionally, the gap between a student's current learning status and learning goals is calculated and transmitted as motivational information, encouraging all learners to pursue their learning goals before beginning a test.

3. *Mentor arrangement module*. A cell phone can serve as a voice communication channel for peer consultation. This module recommends three consulting classmates, called mentors, for question/answer sessions via voice communication. The module judges who has difficulties on some concepts and who can explain concepts to the questioner according to learners' student models. This module transmits mentors' schedule and information to a questioner, who arranges for an appointment with a mentor to solve learning difficulties. The student can then consults with mentors by phone or meet him for a face-to-face discussion.

Fig. 2 shows the system architecture of the ubiquitous learning website. The web-based learning system operates on a Microsoft® Internet Information Services (IIS) web server. Online learning activities of readings, quizzes, discussion, keyword self-assessment, homework submission, and examination are available on the learning website. The web learning system uses the Oracle® database management system (DBMS) as a repository of students' learning behaviors, since its trigger functions can automatically send appropriate messages to learners at the appropriate time. All students' learning behaviors on various learning devices and online test performance were recorded to construct a student model. The student model includes a student's learning preferences and his learning status for every concept in a course. The information-aware system adopts the student model to determine what recommendation should be made and transmitted to a student's cell phone. Additionally, the information-aware system can remind students about scheduled tasks and recommend mentors depending on his/her schedule and skill level in learning concepts.

The concept-mapping technique was applied to the present knowledge structure to guide students in learning. A concept map is a node-link diagram represent a concept using a node and a relationship (for example, "is-a", "related-to," or "part-of") using a link. Novak described the technique of concept mapping as follows: "Concept maps have their origin in the learning movement called constructivism. In particular, constructivists hold that prior knowledge is used as a framework to learn new knowledge" (Novak, 1991). Fig. 3 shows a concept map drawn by a teacher, representing partial object oriented programming knowledge in a Java Programming course. Students need to learn according to specific sequences in the concept map. Although the concept map was not originally designed to define learning sequences, it is integrated with learning sequences herein to build a student model for mentor recommendation. Learning materials and questions were connected to related concepts in the concept map to monitor students' learning status and provide adaptive learning scaffolds.
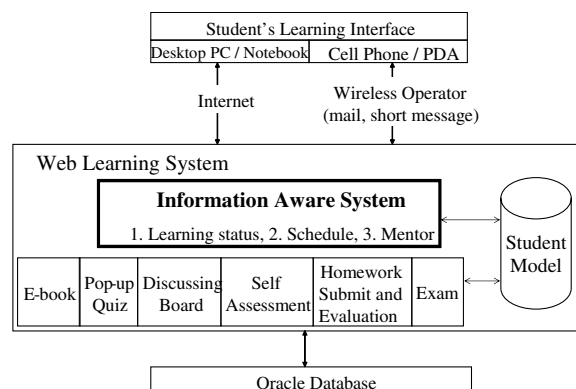

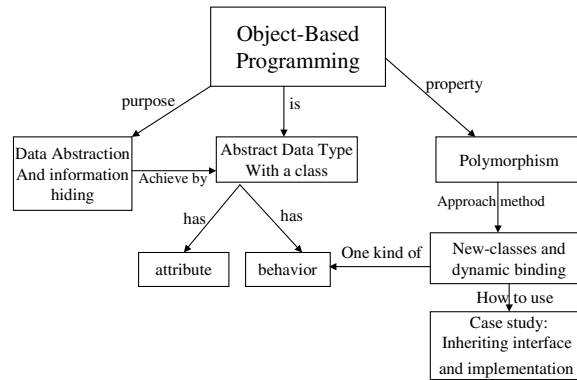Fig. 2. System architecture of the web learning system.

Fig. 3. Concept map present capabilities of object-oriented programming.

Although the concept map in Fig. 3 is a graphic, it is transformed and stored in database for comparison the concept map overlap. To store a concept map in database, a corresponding Table schema is designed as in Table 2.

Each row in the table contains two nodes, and their connected edge, from the concept map in Fig. 3. The last column shows when the teacher taught this concept in classroom. This date information can help the learning system encourage students to catch up with course schedules. When the learning system identifies the concepts that a student should have comprehended but has not it checks this table to determine which concept the student should learn first. The system then reminds students, through the SMS function, to learn or clarify the concept.

2.1. Student model construction

A student model is required to provide students with useful learning information at the right time, and can be constructed from students' web learning portfolios. Therefore, the system needs a student model to track and represent each student's learning status. Fig. 4 shows the design of the information-aware system describing what is being modeled to build the student model, and the three applications devised from the student model. The three modules in the upper part of Fig. 4 were constructed from a student model to provide students with useful learning information at the appropriate time. The student model contains the learning status of every concept; the schedule information for every learner, and the learning sequences for their goals. Consequently, the student model can support a mentor arrangement module for peer consultation, a scheduled reminder module for incoming tasks, and a learning status awareness module to determine proper transmission time.

The student model mainly consists of three components, namely (1) the learning status of each concept; (2) student's personal schedule; and (3) the student's learning goal. A student's learning status is computed from the learning portfolio, which includes the student's self-assessment and test results. Each concept in the course has two indicators representing every student's learning material access times and the learning status for each

Table 2
Database table for storing concept map

| Concept name	Relation name	Related concept	Course progress
Object-based programming	Purpose	Data abstraction and information hiding	2002-Apr-12
Object-based programming	Is	Abstract data type with a class	2002-Apr-12
Object-based programming	Property	Polymorphism	2002-Apr-12
Data abstraction and information hiding	Achieve by	Abstract data type with a class	2002-Apr-16
Abstract data type with a class	Has	Attribute	2002-Apr-19
Abstract data type with a class	Has	Behavior	2002-Apr-19
Polymorphism	Approach method	New-classes and dynamic binding	2002-Apr-23
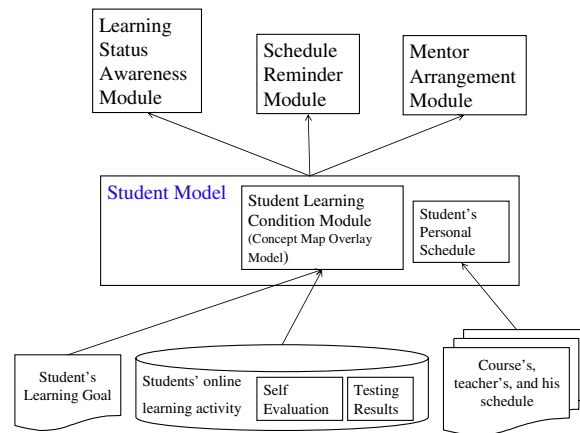
Fig. 4. Design of information aware system.

concept. Additionally, the student model needs every student's schedule to determine the appropriate time to transmit information to students or to remind them to study. An online personal calendar was built to let students manage their tasks and remind them of incoming tasks. The course schedule and assignment also applies to each student's online calendar. Additionally, to encourage students to achieve their learning goal, the system provides students with the online function that helps them to set their learning goal at the beginning of the course. The learning goal is the score that a student want to obtain, and can be modified at any time. The system calculate the difference between a learner's learning goal and his current learning status before a test, to remind a learner of his expected learning level.

The processes and an illustrative example of the construction of a student model are described as follows. In capturing students' learning status for each concept, all clues are generated by analyzing students' online learning behaviors and testing the results. Students log onto the web learning system by a user name and password. Two types of student interaction on the web learning system are recorded as raw data in a database table. One is a student's browsing behavior. For instance, Peter read Section 2 of an online e-book at 6:30 p.m., and read the next section after 3 min. The system records data on Peter's online learning behavior, including his name, action time, access file and duration time. The other type of interaction is a student's response to a prepared question or test. For example, pop-up questions about a concept are displayed on Peter's screen to test him when he logs on to the system. After Peter answers the questions, the system records the test results, including his answer, date, time and quiz number. The student model is built with records of browsing behaviors and quiz results. Fig. 5 shows two types of raw data about learning behaviors and test results, and their relationships to the student model.

Table 1 in Fig. 5 shows students' online e-book reading behaviors. Each row in this table presents information about who had read which document at a specific time, and how long a learner spent reading the document. For instance, the first row of data in Table 1 of Fig. 5 signifies that student 90145000 read document Doc_8_1 on the learning website at 16:30, on April 12, 2002. Additionally, the student had spent 180 s on this document before turning to another document or web page. Students' access information of learning material is stored in the table. Table 2 in Fig. 5 shows students' online quiz results. Each row in this table lists information about who answered what quiz at what time and whether he answered correctly. For example, the first row of data row in this table means that Student 90145000 answered the question Quiz_8_1_1 correctly at 16:33, on April 12 in 2002. To constitute the status indicator in a student model, the table presents a particular student's test results. Table 3 in Fig. 5 shows the student model structure of an individual student's learning status. Each row in this table includes the student ID, concept ID, learning material access status and level of mastery of a concept.

The third column in Table 3 aggregates data in Table 1 to illustrate a student's learning material access status for a concept. The value of this column was accumulated from students' online material accessing behaviors, and those behaviors were recorded as Table 1 in Fig. 5. For example, the Row 1 in Table 1 increases
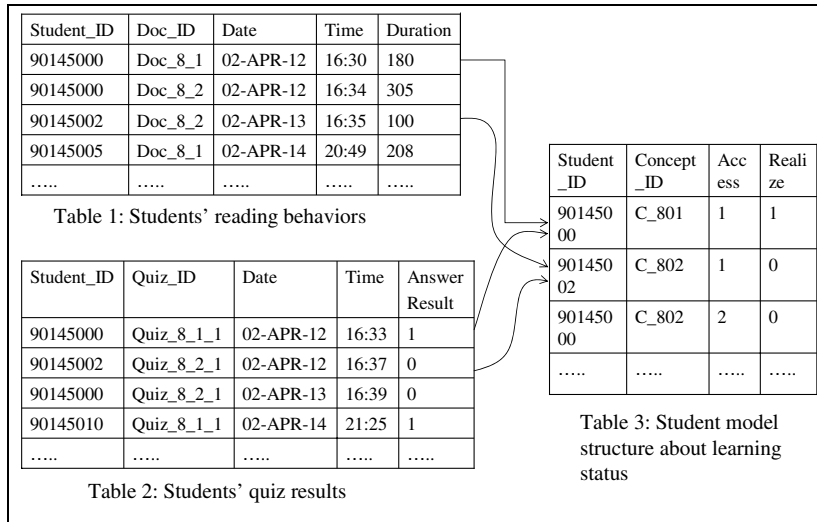
Student_ID	Doc_ID	Date	Time	Duration
90145000	Doc_8_1	02-APR-12	16:30	180
90145000	Doc_8_2	02-APR-12	16:34	305
90145002	Doc_8_2	02-APR-13	16:35	100
90145005	Doc_8_1	02-APR-14	20:49	208
…..	…..	…..	…..	…..

Table 1: Students' reading behaviors

Student_ID	Quiz_ID	Date	Time	Answer Result
90145000	Quiz_8_1_1	02-APR-12	16:33	1
90145002	Quiz_8_2_1	02-APR-12	16:37	0
90145000	Quiz_8_2_1	02-APR-13	16:39	0
90145010	Quiz_8_1_1	02-APR-14	21:25	1
…..	…..	…..	…..	…..

Table 2: Students' quiz results

Student _ID	Concept _ID	Access	Realize
90145000	C_801	1	1
90145002	C_802	1	0
90145000	C_802	2	0
…..	…..	…..	…..

Table 3: Student model structure about learning status

Fig. 5. Tracking and analyzing students' learning status.

Table 3
Suggesting learning concept for each student in SMS messages

Student_ID	Concept	Date	Time	Email address
90145000	Data abstraction	2002-Apr-16	18:00	peter@phs.com.tw
90145001	Information hiding	2002-Apr-16	18:00	rose@phs.com.tw
90145002	Attribute in class	2002-Apr-16	18:02	jeff@phs.com.tw
90145003	Behavior in class	2002-Apr-16	18:02	tom@phs.com.tw

the value in the Column 3 of the Row 1 in Table 3, and the Row 3 in Table 3 thus increases the value in the Column 3 of the Row 3 in Table 3. Column 4 in this table shows a student's level of mastery of a concept. The value of this column was aggregated from students' online test results recorded as Table 2 in Fig. 5. For instance, the Row 1 in Table 2 increases the value in Column 4 of the Row 1 in Table 3, and the Row 2 in Table 3 decreases the value in the Column 4 of the Row 2 in Table 3. Moreover, test results in class were also inputted into Table 2 to adjust student's level of mastery in the student model. Every student's learning status and mastery degree for each concept can be easily assessed after constructing the student model. Consequently, three awareness-reminding modules on the student model can suggest to students what they should learn, whether they have learned enough or who their mentors are.

2.2. Learning status awareness module

This module is recommends to students, which concepts they should learn through SMS messages. The system checks all concepts that the teacher had already taught but students have not yet understood very well. After finding out all concepts that a student should learn, the system selects a concept with the highest learning priority from those concepts according to the concept map hierarchical structure. The system then recommends the concept to the student by an SMS message at the right time. Hence, students become familiar with all concepts in the concept map through a learning sequence defined in the concept map structure.

The use of information in a student model to generate an appropriate concept learning suggestion is described below. Table 3 in Fig. 5 shows the learning status of each concept that students have learned. To determine the concept that a student should learn first, the student model table is queried to identify all the concepts that the student has not learned very well. The criterion for selecting a concept for a learner depends on whether the grades in the student model are already higher than his learning goal. After all concepts that a

student did not learn well are identified from the student model table, they are ranked according to the concept map structural sequence. The inner joint operation between the student model and concept map tables (see Table 2) can rank concepts by learning priority. After finding a priority concept for a learner, this module transmits the recommendation via an SMS message when the personal calendar indicates that the learner is free.

This system does not transmit learning materials to a student's cell phone directory. Each student is required to set the incoming email alert function on in his cell phone, so that the learning system's emergent messages are transmitted to destined email addresses. Students are notified of incoming email by SMS messages. Thus, the system simply needs to send a suggestion to a student's email box without routing messages to external message transferring services. To transmit a notification automatically, a database trigger is adopted to assist message transfer. A table is created, as shown in Table 3, to handle the information to be transmitted to learners. An Event–Condition–Action rule is triggered to notify students by email when a row is inserted into this table. The last column of the table is the email address for notification.

The system regularly checks every student's online calendar to see whether students have time to check the message and respond to it accordingly. When a suitable time is found, the learning status awareness module first chooses a concept name. The concept name with this student's information and date/time is inserted into Table 3 as a new row. Consequently, the database trigger transfers this message to the student's email box, and the student is alerted immediately by an SMS message. A database trigger, which is often called an Event–Condition–Action rule, acts as follows:

1. Event = INSERT, UPDATE, or DELETE event.
2. Condition = a test as in a where-clause for whether or not the trigger applies.
3. Action = one or more instructions or actions.

An example of database trigger syntax is shown below:

CREATE TRIGGER Learning_status_aware
  ON Learning_status_aware
  FOR INSERT
  AS EXEC master...xp_sendmail "E-Address", "Now you should learn" + Concept

The trigger script is executed or "fired" when a new datum named "*Learning_status_aware*" is inserted into the table. The trigger checks the satisfied condition, and sends an email to the address with the content "Now you should learn CONCEPT NAME". The recommended concept name is from the "Concept" column in Table 3. The address information is from the "Email address" column in Table 3.

2.3. Schedule reminder module

To let students follow a teacher's instruction closely, the schedule reminder module allows students and teachers to edit their online calendars concurrently. The course schedule and student's personal online calendar are created on a web server and stored in a database table. Each student has a personal calendar in the learning website, and manages it using a web browser. A teacher can edit course schedules and instructional plans on the learning website. Course pre-defined schedule and teacher's instructional plans immediately affect students' personal online calendar. If any conflict exists between a personal and course schedule, then the system notifies the relevant learner (by SMS message) to modify his personal schedule. Students are notified about which task is coming through the SMS message according to their online calendars.

Gap analysis module determines the gap between every student's current learning status and his learning goal to let him know the gap to achieve his goal with motives. For each student, the student model includes a variable storing the up-to-date learning goal, which is the grade (0–100) that a student wishes to obtain. This module averages the "concepts understanding" status of a student from his student model, and compares it with his learning goal. If the averaged value is smaller than the learning goal, then this module reminds the student of the gap by SMS before the exam takes place, urging him to practice further.
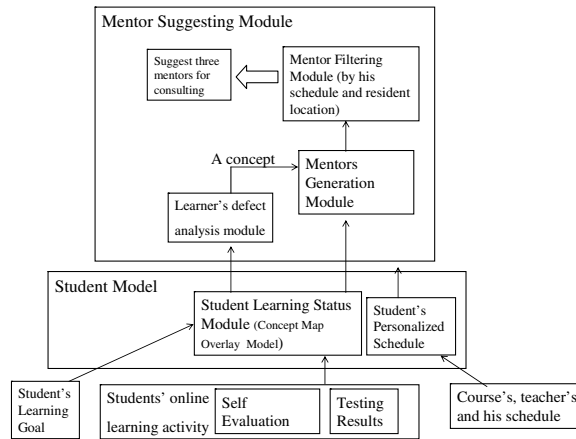
Fig. 6. Workflow diagram of mentor arrangement module.

2.4. Mentor arrangement module

This module is designed to support students' peer mentoring or coaching. The system suggests three mentors among classmates for consultation about a specific concept. After receiving this recommendation, the consulter can discuss this question by phone or face-to-face. Fig. 6 shows the workflow diagram of the mentor arrangement module. The mentor arrangement module determines who can be a mentor according to each student's learning status and schedule in the student model. A student's learning status table (see Table 3 of Fig. 5) determines every learner's ability to answer questions in a concept, while the schedule information indicates who has free time to help peers.

The mentor arrangement module first checks students' schedules in their personal calendars to determine who has time to learn. After finding a student, the system checks his learning status table in the student model to find a concept with which he is not very familiar. Restated, the system identifies concepts for which a student's learning status does not exceed his learning goal, and suggests that the student consult with others about it. The module then searches the learning status table where some students with learning status values are higher than that of the consulter to act as mentors. The module also filters out some mentors who have no time at that moment. The module also checks students' residential locations to find neighboring advantage if they want a face-to-face discussing. Finally, a message with three mentors' details and one concept name are transmitted to consulter's phone for peer consulting.

3. Experiment results

An experiment was conducted to evaluate the effects of the three awareness reminder modules. Hence, the experimental results of the three modules and analysis of system logs during the experiment are reported. The experiment was performed at the National Central University in Taiwan, and the subjects were 54 students from the course named ''*Introduction to Computer Science*''. All subjects were freshmen majoring in Computer Science. At the beginning of the course, all students learned in a conventional classroom and used the web-based learning system after class. Students were then trained for two weeks on how to access the web-based learning system through a cell phone and PDA. Just before the midterm in the eighth week, 27 volunteer students (the experiment group) in the class were provided with the information awareness reminder mechanism through mobile devices to support their learning, while the other 27 students (the control group) accessed the same information only using a desktop PC or laptop. Since the number of available mobile devices was restricted, the groups of students were made as heterogeneous as possible in terms of characteristics such as accessibility of PC or laptop, pervious academic performance, system acceptability, and sex.

The students' midterm scores in eighth week were taken as pretest results, then volunteers began to use the mobile devices for four weeks. The volunteers were equipped with a cell phone and a PDA. The cell phone was

a SANYO PHS-J88, and the PDA was a Pocket PC powered by Microsoft Windows CE. The information awareness reminder system transmitted messages to students through their cell phones, and students of the experiment group could link to the learning website immediately using a cell phone and PDA. Although students in the control group could not immediately obtain the instant messages and access website, they would obtain those messages when logging into the web learning system through a Desktop PC or laptop. Four tests were conducted at the end of each week to show the subjects' behaviors as affected by the system. In other words, one test was performed weekly before the post-test to evaluate the difference between the groups affected by cell phone support. The effect of the three mobile supporting modules on the experimental group was measured.

3.1. Experimental results about the learning status awareness module

The first part of experimental results is to test whether the learning status awareness reminder mechanism can improve students' weekly test results, that is, their academic performance. The system recommended concepts and quizzes for students to learn through their cell phones. After receiving a suggestion, students were asked whether it was useful to their learning. Table 4 shows the students' satisfaction rates with the suggestions, and indicates that 73.4% of concept suggestions and 79.8% of quiz suggestions were helpful.

Additionally, weekly test results reveal that using mobile devices with an awareness reminder mechanism can improve learning performance. In the pretest, the grades of the experiment group were 4.3% higher than those of the control group. The grades of the experiment group outperformed the control group by 12%, 5.3%, 13%, and 9% in four weekly tests, respectively. Moreover, t-test analysis shows that the test results of the experimental group were significantly different from those of the control group, indicating that this module can signally enhance the learning performance of the experiment group.

The pre-test and average of four weekly test results were taken to evaluate whether students equipped with mobile devices perform better then the control groups. The average improvement in the grades of members of the control group was 6.14, while that of the experiment group was 7.81. However, the independent sample t-test result revealed no significant differences between the control and experimental groups on the improvement of weekly tests ($t = -0.393$, $p = 0.696$). The detailed weekly test results of the students indicate that most students in the top 10% of the class were not affected in their test results during the experiment, while some students in the control group significantly increased their weekly test scores. The grades of a few students in the experimental group fell in grades. The learning system logs reveal that these students generally disregarded the system's reminder SMS messages. Consequently, the independent sample t-test had no significant difference, although the average grades of the experimental group were better than those of the control group in weekly tests.

Accordingly, another analysis was conducted to determine whether the experimental students' grades had a significant difference before and after experiment. The paired-sample t-test results revealed significant differences between pre-test and post-test ($t = -2.703$, $p = 0.012 < 0.05$). These results imply that most students under these supports can gain higher grades on weekly tests. Consequently, further analyses were carried out to identify the students who would be affected significantly by the support system according to their pretest results. The experimental group was split into three subgroups based on the order of their pre-test grades (higher level students, middle level students, lower level students) to determine which students would be significantly aided by the mobile learning system. The paired-samples t-test results in those three categories for pre-test and post-test are as follows:

Table 4
Students' satisfaction rate about learning material and quiz suggestions

Rate of useful for learning/message times	Strongly agree (%)	Agree (%)	No comment (%)	Disagree (%)	Strongly disagree (%)
Concept/(248 times)	15.7	57.7	21.4	2.0	3.2
Quiz/(311 times)	12.9	66.9	14.5	1.9	3.9

Higher students: $m_1 = 80.60$, $m_2 = 80.70$, $t = 0.117$, $p = 0.91$.
Middle students: $m_1 = 65.44$, $m_2 = 70.06$, $t = -2.226$, $p = 0.057$.
Lower students: $m_1 = 37.89$, $m_2 = 56.26$, $t = -3.067$, $p = 0.015 < 0.05$.

The results reveal that the system has almost has no effect on those students in the higher subgroup (33%). However, the reminder system can significantly improve the learning performance of students in the middle and lower subgroups (66%), particularly in the lower subgroup (33%).

3.2. Experimental results about the schedule reminder module

The aim of the second part of the experiment was to determine whether the schedule reminder module could increase the accomplishment rate of the assigned tasks. Students in the experimental group failed to finish 7.9% of assigned tasks, while students in the control group did not finish 23.8% of assigned tasks. The experimental results show that the schedule reminder module can enhance the students' task completion rate. Although the accomplishment rates of the assigned tasks were mainly influenced by the schedule reminder module, the mentor arrangement module can affect task accomplishment rate by mentors' supports. Therefore, this section compares the effects of the mentor arrangement module with those of the schedule reminder module.

Another analysis is to evaluate whether or not the learning gap reports in this module can help students achieve their learning goals. Table 5 shows students' learning goals and their rates of achievement of learning goals in four weekly tests. In the first week, students in the experiment group set their learning goal grades (students who set their grades is 76.7 in average) similar to students in the control group (the average grades is 75.2). Although both groups had low goal achievement rates in the first week, the goal achievement rate of the experiment group was clearly higher then that of the control group. The average learning goal of the control group changed from the average number of 75.2–70.0 in the second week. Students in the control group seemed to lower their learning goals to match their weekly test results in the following weeks. However, the goals-achieved rates increased in the experimental group without an obvious decrease in weekly learning goals.

The result shows that the experiment group had an average achievement rate of 50.8%, while the control group had an average achievement rate of 34.15%. The average learning goals (74.35) in the experimental group were also higher than those of the control group (70.03), revealing that the gap analysis mechanism in this module can encourage students to pursue their learning goals and gain higher grades.

3.3. Experimental results about the mentor arrangement module

The third part of the experiment is designed to determine whether the mentor arrangement module in a learning system can help students consult with appropriate classmates, and whether they are satisfied with consultation results. In the experiment, students were asked to answer two questions after consulting with the recommended mentors. The first question is, ''Before I discuss with the recommended mentors, do I think they can solve my problem?'' The second question is, ''After consulting the mentor, has my problem been solved?'' Table 6 shows that most students think the recommended mentors can teach them in the specific concepts. Most students ($84.8\% = 33.3 + 51.5\%$) agree that the mentor can help them solve their problems. Addition-

Table 5
Comparison of students' average grade and achieved percent of learning goal

	First week		Second week		Third week		Forth week	
	Average grade of goal	Goal achieved rate (%)	Average grade of goal	Goal achieved rate (%)	Average grade of goal	Goal achieved rate (%)	Average grade of goal	Goal achieved rate (%)
Experiment group	76.7	29.6	75.6	44.4	72.4	60	72.7	69.2
Control group	75.2	9.5	70.0	42	67.5	33	67.4	52.1

Table 6
Questioner's opinion about mentor suggestion

	Strongly agree (%)	Agree (%)	No comment (%)	Disagree (%)	Strongly disagree (%)
Question 1	33.3	51.5	12.1	3	0
Question 2	30.3	54.5	12.1	3	0

Table 7
Login times of experiment group and control group

	First week	Second week	Third week	Forth week
Experimental group	551	507	504	501
Control group	200	241	223	208

ally, most students (84.8% = 30.3 + 54.5%) agree that their problem has been solved after consulting the mentor. These data indicate that the module can arrange appropriate mentors for students to consult.

3.4. Log analysis of the ubiquitous learning system

Logs of students' online behaviors were gathered to indicate their use of a particular function in the ubiquitous learning system. Students in the control group could only log into the web learning system by a desktop or laptop PC. Students in the experiment group could use a desktop PC, laptop, PDA or cell phone to log into the system, and hence could browsing at any time and from anywhere. Table 7 shows the login times of the control group and experiment group for each week. Table 7 reveals students in the experimental group logged in for twice the time of those in the control group. Although students in the experiment group had more opportunities to log in than students in the control group, the double login times is too obvious to exclude the reminders that pulled them back to the system. Table 7 demonstrates that the reminder SMS messages indeed pulled students back to the ubiquitous learning system.

The most popular types of information pushed through cell phones are listed as follows in descending order of satisfaction rate: quiz (79.8%), learning material recommendation (73.4%), homework deadline reminders (69.2%), weekly test results (67.8%), test time reminders (65%), and gap analysis (62.8%). Most students like to answer a quiz on their cell phones, just as they like playing games. Additionally, the learning material recommendation information is also very popular with the students, because the information indicates what they should learn. The task reminding functions were also very helpful for preventing students from forgetting homework or a test, even for students who had already prepared. The gap analysis information intended to push students toward their goal was not very useful, because some students did not believe its authenticity.

Each learning function in a PDA and cell phone used by a student was recorded to reveal the function usage rates. Students often used PDAs for reading the news. The second most frequently used function of PDAs was to read discussion content. The third function was to check the learning status of classmates. The most popular function of cell phones was reading the news on a learning web site, followed by checking homework submission status and homework correction results. Most students were very interested in what happens in this class. A cell phone or PDA seems to be very useful for students to check news. Students are also interested in reading discussion documents, but very few students used a PDA to respond to the discussion. This does not mean students do not want to interact on a discussion board. Students do not like to input through a PDA because many of them preferred to join discussions using a desktop PC or laptop.

4. Conclusion

To support and motivate student learning, this study developed a ubiquitous learning environment for students to learn by a desktop PC, laptop, PDA and cell phone. The learning website can concurrently support students to learn with any one of those learning devices. All students' learning behaviors, preferences, learning goals, schedule and test results were recorded in a database to built a student model for adaptive learning. The

SMS function in a cell phone was adopted to transfer, at the right time, helpful information about aware learning status, reminding tasks and facilitative peer support. Three modules for information awareness of learning context were developed to scaffold students according to their learning status awareness, schedule reminders and mentor arrangement. In the design of those three modules, the concept map technique was integrated with the student model to reveal learning status and learning sequence. Students' online learning behaviors and test results were analyzed to offer them appropriate learning information. Students' learning goals and their schedules were also considered for learning content and delivery time. The analysis of experimental results and system logs indicate that the testing results, task-accomplished rate and learning-goal-achieved rate can be improved by the support of the ubiquitous learning website. Most significantly, this study shows the pedagogical potential and benefits of adopting the ubiquitous learning environment for integrating web-based and mobile learning.

Acknowledgements

References

Anhalt, J., Smailagic, A., Siewiorek, D. P., Gemperle, F., Salber, D., Weber, S., et al. (2001). Toward context-aware computing: experiences and lessons. *IEEE Intelligent Systems, 16*(3), 38–46.

Bull, S., Brna, P., & Pain, H. (1995). Extending the scope of the student model. *User Modeling and User-Adapted Interaction, 5*(1), 45–65.

Chang, C. K., Chen, G. D., & Ou, K. L. (1998). Student portfolio analysis for decision support of web based classroom teacher by data cube technology. *Journal of Educational Computing Research, 19*(3), 307–328.

Chang, C. Y., Sheu, J. P., & Chan, T. W. (2003). Concept and design of ad hoc and mobile classrooms. *Journal of Computer Assisted Learning, 19*(3), 336–346.

Mari, K. A. (2000). Context-aware applications survey, *Internetworking seminar (Tik-110.551)*, Helsinki University of Technology.

Novak, J. D. (1991). Clarify with concept maps: a tool for students and teachers alike. *The Science Teacher, 58*(7), 45–49.

Rieger, R., & Gay, G. (1997). Using mobile computing to enhance field study. In *Proceedings of CSCL'97* (pp. 215–223).

Roschelle, J., & Pea, R. (2002). A walk on the WILD side: How wireless handhelds may change CSCL. In *Proceedings of CSCL'02*.

Seppälä, P., & Alamäki, H. (2003). Mobile learning in teacher training. *Journal of Computer Assisted Learning, 19*(3), 330–335.

Soloway, E., Grant, W., Tinker, R., Roschelle, J., Mills, M., Resnick, M., et al. (1999). Science in the palms of their hands. *Communications of the ACM, 42*(8), 21–27.

Staudt, C., & Hsi, S. (1999). Synergy projects and pocket computers. Concord Consortium Newsletter. Available from http://www.concord.org/library/1999spring/synergyproj.html.

Trifonova, A., & Ronchetti, M. (2004). A general architecture to support mobility in learning. In *Fourth IEEE international conference on advanced learning technologies (ICALT'04)* (pp. 26–30).

Want, R., Hopper, A., Falcao, V., & Gibbons, J. (1992). The active badge location system. *ACM Transactions on Information Systems, 10*(1), 91–102.

Weiser, M. (1993). Some computer science issues in ubiquitous computing. *Communications of the ACM, 36*(7), 75–84.