Criteria, Strategies and Research Issues of Context-Aware Ubiquitous Learning

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ABSTRACT

Recent progress in wireless and sensor technologies has lead to a new development of learning environments, called context-aware ubiquitous learning environment, which is able to sense the situation of learners and provide adaptive supports. Many researchers have been investigating the development of such new learning environments; nevertheless, the criteria of establishing a context-aware ubiquitous learning environment have not yet been clearly defined, not to mention the strategies of conducting effective learning activities. To resolve these problems, this paper presents the basic criteria, strategies, and research issues of context-aware ubiquitous learning, and identifies the necessary check items as well for the development of such learning environment. Illustrative examples of conducting context-aware ubiquitous learning activities and the requirements of setting up such learning environment are also presented at the end of this paper.

Keywords

Ubiquitous learning, context awareness, science education, wireless networks, ubiquitous computing

1. Introduction

In past decade, the rapid advance of broadband and wireless Internet technologies has promoted the utilization of wireless applications in our daily lives. A variety of invisible embedded devices and corresponding software components have also been developed and connected to the Internet. Ubiquitous computing is referred to a new technology which enables people to seamlessly utilize huge amounts and various kinds of "functional objects" anytime and anywhere through network connections (Rodríguez & Favela, 2003; Minami et al., 2004). Another feature of ubiquitous computing is the use of wireless communication objects embedded with sensors to detect users and environment information for the provision of personalized services (e.g., RFID, Radio-Frequency Identification).

In recent years, e-learning researchers noticed that the progress of wireless communication and sensor technologies have evolved the research issues of e-learning to mobile learning (m-learning), and now is evolving from m-learning to ubiquitous learning (u-learning). Several significant characteristics of u-learning, which make it different from conventional e-learning, have been discussed, including seamless services, context-aware services, and adaptive services (Bomsdorf, 2005; Hwang, 2006; Yang et al., 2006; Yang et al., 2007). In an ideal u-learning environment, computing, communication, and sensor devices are embedded and integrated into learners' daily life to make learning immersive. Based on this concept, Yang (2006) proposed a learning environment facilitated with context-aware peer to peer search to empower learning resource finding and sharing.

Nevertheless, as learning environments change so quickly, u-learning has not yet been clearly defined, not to mention the strategies for conducting learning activities in such an environment. To cope with these problems, we attempt to propose the criteria for establishing a u-learning environment in this paper; moreover, the characteristics of m-learning and u-learning are compared in order to more clearly identify the features and potentials of u-learning.

Finally, several strategies for designing learning activities in a u-learning environment, and the relevant research issues are given as a useful reference for those who are interested in this field.

2. Characteristics of a Ubiquitous Computing Environment

To develop context-aware and seamlessly integrated Internet environments, a variety of new techniques and products concerning ubiquitous computing have been developed in recent years, such as sensors and actuators, RFID tags and cards, wireless communication, mobile phones, PDA (Personal Digital Assistant) and wearable computers.

From the system designer's point of view, physical integration and spontaneous interoperation are the two main characteristics of ubiquitous computing systems (Kindberg & Fox, 2002). Physical integration means that a ubiquitous computing system involves some integration between computing nodes and the physical world. For example, a smart coffee cup, such as a Media-Cup (Beigl et al.,, 2001), serves as a coffee cup in the usual way, but also contains sensing, processing and networking elements that let it communicate its state (full or empty, held or put down), enabling the cup to give hints about the state of the cup, as well as its owner. Moreover, consider a smart meeting room that senses the presence of users in meetings, records their actions (Abowd, 1999), and provides services as they sit at a table or talk in front of a whiteboard (Ponnekanti et al., 2001). The room contains digital furniture such as chairs with sensors, whiteboards that record what is written on them, and projectors that can be activated from anywhere in the room, using a PDA.

In the meantime, a ubiquitous system must spontaneously interoperate in changing environments. A component interoperates spontaneously if it interacts with a set of communicating components that can change both identity and functionality over time as its circumstances change (Kindberg & Fox, 2002). A spontaneously interacting component changes partners during its normal operation, as it moves or as other components enter its environment; it changes partners without needing new software or parameters (Feeney et al., 2001). For example, to seamlessly hold a video conference, the system needs to immediately locate the nearest functional objects, such as a CCD camera and display equipment, for each attendee. If the attendee moves toward another room, the system will change devices according to the user's context, so that the video conference can be seamlessly continued. If the attendee switches his or her device from a notebook with a 100 Mbps local area network to a PDA with a lower-speed wireless network, the system will locate additional translation coders or drivers accordingly.

From the user's point of view, in a ubiquitous computing environment, anyone can make use of computers that are embedded everywhere in a public environment, at any time. A user equipped with a mobile device can connect to any of them, and access the network by using wireless communication technologies (Uemukai et al., 2004). Moreover, not only can a user access the network actively, but computers around the user can recognize the user's behavior and offer various services according to the user's situation, the mobile terminal's facility, the network bandwidth, and so on (Cheng & Marsic, 2002). User assistance via ubiquitous computing technologies is realized by providing users with proper decisions or decision alternatives. That is, a ubiquitous computing technology-equipped system supplies users with timely information and relevant services by automatically sensing users' various context data, and smartly generating proper results (Kwon et al., 2005). Therefore, by employing this new technology in education, the learning system is not only adapted to the individual's needs, but is also actively involved in his or her learning activity. Hence, the ideas of using u-computing technology for learning concur with the pedagogical theory of constructivism. In the frame of constructivism, educators need to provide student-centered learning environments to facilitate the active construction of each individual learner (e.g., Fosnot, 1996). It also highlights the student's prior knowledge and cognitive apprenticeship (e.g., Tsai, 2001, 2005). Clearly, well-developed learning systems that employ u-computing technologies can be highly adaptive, based on the student's prior knowledge and existing performance to provide proper guidance or apprenticeship for each learner. In the following sections, the ideas and strategies of using u-computing technologies in designing learning activities are presented; in addition, several illustrative examples are given to demonstrate the ideas in detail.

3. Criteria of Context-Aware Ubiquitous Learning

Although u-learning has attracted much attention from the academia, the criteria of developing a u-learning environment have not been clearly defined. Till now, researchers have different views of the term "u-learning". One

view is “anywhere and anytime learning”, which is a very broad-sense definition of u-learning. With this definition, any learning environment that allows students to access learning content in any location at any time can be called a u-learning environment, no matter whether wireless communications or mobile devices are employed or not. From this viewpoint, the mobile learning environment which allows students to access learning content via mobile devices with wireless communications is a special case of the broad-sense definition of u-learning.

It is clearly identified through the above discussion that u-learning is not equal to “learning with u-computing technology”, which emphasizes not only the usage of wireless communications, but also the sensor technology (Hwang et al., 2007). More precisely speaking, “learning with u-computing technology” is a special case of mobile learning. In the following discussion, we shall focus on such a special definition of u-learning that employs mobile devices, wireless communications and sensor technologies in learning activities, called “context-aware u-learning”, to distinguish it from the broad-sense definition of u-learning, and the concept of mobile learning. Figure 1 shows the relationships amongst u-learning, mobile learning, u-computing in learning and the newly defined “context-aware u-learning”.

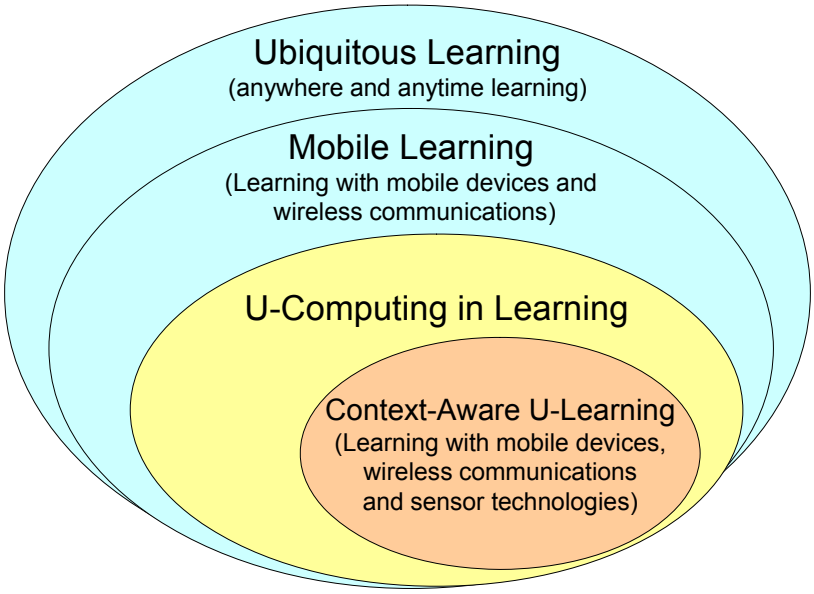

Figure 1. Relationships amongst u-learning, mobile learning, u-computing in learning and “context-aware u-learning”

The context-aware feature of u-computing environments allows the learning system to better understand the learner’s behavior and the timely environmental parameters in the real world, such as the locations and behavior of the learner, and the temperature and humidity of the learning environment (Kawahara et al., 2003). Such contexts could be brief or detailed; for example, the location of the user could be described by a zip code or a physical address.

Among various contexts that can be sensed, researchers have indicated that “time” and “location” may be the most important and fundamental parameters for recognizing and describing a learner’s context (Lonsdale et al., 2003). For example, Ogata and Yano (2004) presented a u-learning system which has been used to help students to learn Japanese in real-world situations. The systems can provide learners with appropriate expressions according to different contexts (e.g., occasions or locations) via mobile devices (e.g., PDA). Rogers et al. (2005) integrated the learning experiences of indoor and outdoor activities by observation in the working scene. Learners are not only capable of getting data, voice and images from the scene by observation, but also of gathering related information from learning activities via wireless networks. Recently, Joiner et al. (2006) presented their studies of applying context-aware devices to education by providing students with timely vocal statements related to specific activities in real conditions.

Meanwhile, researchers have attempted to identify principles and methods for designing u-learning activities (Yang et al., 2007). For example, Cheng et al. (2005) demonstrated how a u-learning system provides adaptive services via

four steps: (1) Setting instructional requirements for each of the learner's learning actions. (2) Detecting the learner's behaviors. (3) Comparing the requirements with the corresponding learning behaviors. (4) Providing personal support to the learner.

Accordingly, the potential criteria of a context-aware u-learning environment are given as follows:

1. A context-aware u-learning environment is context-aware; that is, the learner's situation or the situation of the real-world environment in which the learner is located can be sensed, implying that the system is able to conduct the learning activities in the real world.
2. A context-aware u-learning environment is able to offer more adaptive supports to the learners by taking into account their learning behaviors and contexts in both the cyber world and the real world.
3. A context-aware u-learning environment can actively provide personalized supports or hints to the learners in the right way, in the right place, and at the right time, based on the personal and environmental contexts in the real world, as well as the profile and learning portfolio of the learner.
4. A context-aware ubiquitous learning environment enables seamless learning from place to place within the predefined area.
5. A context-aware ubiquitous learning environment is able to adapt the subject content to meet the functions of various mobile devices.

Such a learning environment basically consists of the following components:

1. A set of sensors that is used to detect personal contexts (e.g., the location and body temperature of the learners) and environmental contexts (e.g., the temperature and humidity of the learning environment).
2. A server that records the contexts, and provides active and passive supports to the learners.
3. A mobile learning device for each learner with which the learner can receive support or guidance from the server, as well as being able to access information on the Internet.
4. Wireless networks that enable communication among the mobile learning devices, the sensors and the server.

Based on those criteria, a comparison of a context-aware u-learning system and a mobile learning system is presented in Table 1. The major differences are due to the context awareness and active action initiative of the systems, which enable the u-learning system to train and evaluate the real-world observation skills and problem-solving abilities of the learner (Hwang, 2006).

Table 1. Comparisons of context-aware u-learning systems and m-learning systems

Learning system / Item	M-Learning System	Context-Aware U-Learning System
Awareness of learner contexts	By accessing the learning portfolio database.	By accessing the learning portfolio database and sensing the personal contexts (e.g., location and body temperature) and environmental situations of the learner in the real world.
Accessing learning services or teaching materials	Learners actively access the system via wireless networks. That is, the learning system usually provides services passively.	The system actively provides personalized services to the learners based on the learner's contexts.
Content of the learning portfolio	Recording the online behaviors of the learner.	Recording the online behaviors, the real-world behaviors and the corresponding environmental information of the learner.
Personalized support	Based on the learner's profile and online behaviors in the database.	Based on the personal behaviors and environmental situations of the learner in the real world.
Seamless learning feature	Changing learning devices or learning in moving will interrupt the learning activities.	Learning services will not be interrupted even though the learner is moving from place to place and the environment (including the learning devices and the networks) is changing.

According to Table 1, context-aware u-learning can provide more adaptive service than m-learning (or the broad sense definition of u-learning), as it takes more consideration of the learner's individual information of various

sources in the context. Also, context-aware u-learning is more convenient, as the system adapts the instructional content to meet the functions of different mobile devices.

4. Strategies of Learning Activity Design for Context-Aware U-Learning

To conduct learning activities in a context-aware u-learning environment, it is necessary to define the situation parameters taken into account (Yang et al., 2007). For a learning activity conducted in the real world, there are five types of situation parameters, as shown in the following:

- Personal contexts sensed by the system: includes the learner's location and time of arrival, temperature, level of perspiration, heartbeat, blood pressure, etc.
- Environmental contexts sensed by the system: includes the sensor's ID and location, the temperature, humidity, air ingredients, and other parameters of the environment around the sensor, and the objects that are approaching the sensor.
- Feedback from the learner via the mobile learning device: includes the observed or sensed data of the target items (such as environmental temperature and acid value of water, air pollution, shape and color of a tree, machine status after performing an operation), acquired photos or interactions with the learning system (e.g., the answers to the test items or the log for operating the system).
- Personal data retrieved from databases: includes the learner's profile and learning portfolio, such as the pre-defined schedule of the learner, expected starting time of a learning activity, the longest and shortest acceptable time period of a learning activity, the learning place, the learning paths or sequences of a course, the constraints or prohibitions of a course of learning activity, etc.
- Environmental data retrieved from databases: includes the detailed information of the learning site, such as the schedule of learning activities arranged at the site, the constraints or management rules of the site, notes for using the site, the equipment located at the site, the persons who use or manage the site, etc.

Based on these situation parameters, twelve context–aware u-learning models are proposed in Table 2, which can be used to conduct learning activities and to assess the learning performance of the students based on their real-world and online behaviors.

Table 2. Twelve models for conducting context-aware u-learning activities

ID and Name of the Model	U-Learning Strategies and Examples
ULS_1 Learning in the real world with online guidance	The students learn in the real world and are guided by the system, based on the personal profile, portfolio and real-world data collected by the sensors. E.g., for the student who takes an experimental chemistry course, hints are provided automatically based on his or her real-world actions during the experiment procedure.
ULS_2 Learning in the real world with online support	The students learn in the real world, and support is automatically provided by the system based on the personal profile, portfolio and real-world data collected by the sensors. E.g., for the student who is learning to identify the types of plants on campus, relevant information concerning the features of each type of plant is provided automatically based on his or her location and the plants around him or her.
ULS_3 Online test based on real-world object observations	The student is asked to answer questions presented on the screen of the mobile device by observing the real-world objects. E.g., "What is the type of tree located in front of you?"
ULS_4 Real object observation	The student is asked to find the object in the real world, based on the question presented in the mobile device. E.g., "Observe the plants around you and find the plant that is most similar to the one shown on the screen."
ULS_5 Collect data in the real world via observations	The students are asked to collect data by observing objects in the real world, and transfer the data to the server via wireless communications. E.g., "Observe the plants in this area and transfer the data (including the photos you take and your own descriptions of the features of each plant) to the server."
ULS_6 Collect data in the real world via sensors	The students are asked to collect data by sensing objects in the real world, and report what they have found. E.g., "Find three different samples of water, and report any contaminant found by using

	the sensors."
ULS_7 Identification of a real-world object	Students are asked to answer the questions concerning the identification of the real-world objects. E.g., "What is the name of the insect shown by the teacher?"
ULS_8 Observations of the learning environment	Students are asked to answer the questions concerning the observation of the learning environment around them. E.g., "Observe the school garden, and upload the names of all of the insects you find."
ULS_9 Problem-solving via experiments	Solve problems by designing experiments in the real world and finding hints on the Internet E.g., "Consider the balloon given by the teacher; design an experiment to find the relationship between the payload mass and the altitude of the balloon."
ULS_{10} Real world observation with online data searching	The students are asked to observe the real-world objects and find solutions by accessing the network. E.g., "Observe the building in front of you; find detailed data about it online."
ULS_{11} Cooperative data collecting	A group of students is asked to cooperatively collect data in the real world, and discuss their findings with others via mobile devices. E.g., "Cooperatively draw a map of the school by measuring each area, and integrate the collected data."
ULS_{12} Cooperative problem solving	The students are asked to cooperatively solve problems in the real world by discussing through mobile devices. E.g., "Search each corner of the school and find the evidence that can be used to determine the degree of air pollution."

According to Table 2, u-learning can be used in different ways. It should be noted that the difference between models ULS_1 and ULS_2 is that ULS_1 provides more scaffolding while ULS_2 offers online assistance only when the learner requests it.

5. Illustrative Examples of Context-Aware U-Learning

To address the context-aware u-learning activities in more detail, a learning environment with several illustrative examples of learning activities is given in this section. Consider the "Identification of Plants" unit in the Natural Science course of an elementary school. Figure 2 shows the context-aware u-learning environment with RFID sensors and wireless networks. Each target plant has an RFID tag attached to it which records the identification data of the plant, and each student is equipped with a PDA with an RFID reader which can read the data from the tag if the student is close enough. Once the u-learning system identifies the plant, relevant information can be read from the plant database in the server via wireless communications.

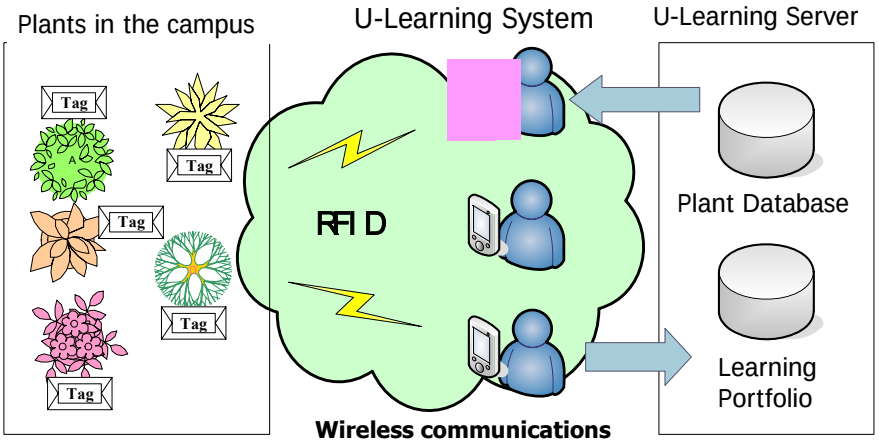

Figure 2. Illustrative example of a context-aware u-learning environment

Case 1: Learning in the real world with on-line guidance

> Context-aware **u-learning system:** Now we are going to learn to identify the bushes on campus. Can you see the plant in front of you?
> **Student:** Yes.
> Context-aware **u-learning system:** Can you identify the plant.
> **Student:** No.
> Context-aware **u-learning system:** What is the color of its leaves?
> **Student:** Green.
> Context-aware **u-learning system:** Does the plant have one trunk?
> **Student:** No.
> Context-aware **u-learning system:** Read the descriptions of the following plants (after the student clicks the "continue" bottom, three bushes are depicted in sequence, as shown in Figure 3). There are three candidate plants, Lantana, Nandin and Murraya Paniculata Jack. Which one do you think this plant is?

Figure 3. Candidate plants shown on the mobile learning device

> **Student:** Nandin.
> **Context-aware u-learning system:** Great! Now turn right, and walk to the corner of the campus.
(The student follows the instruction.)
> **Context-aware u-learning system:** Can you see the plant in front of you?
> **Student:** Yes.
> **Context-aware u-learning system:** Can you identify the plant.
> **Student:** Yes.
> **Context-aware u-learning system:** What is its name?
> **Student:** Lantana.
> **Context-aware u-learning system:** Great! Now look around the campus. Can you find any other bushes?
> **Student:** Yes.
> **Context-aware u-learning system:** Please walk to the front of the plant.
(The student follows the instruction, and walks toward a Nandin.)
> **Context-aware u-learning system:** Is the stem of the plant woody?
> **Student:** Yes.
> **Context-aware u-learning system:** Does the plant have one trunk?
> **Student:** No.
> **Context-aware u-learning system:** What is the color of its leaves?
> **Student:** Green.
Context-aware u-learning system: What is its name?
> **Student:** Nandin.

> **Context-aware u-learning system:** Great! Now look around the campus, can you find any other bushes?
> **Student:** Yes.
> **Context-aware u-learning system:** Please walk to the front of the plant.
(The student follows the instruction.)
> **Context-aware u-learning system:** What is its name?
> **Student:** Murraya Paniculata Jack.
> **> Context-aware u-learning system:** Great! It seems that you are able to identify all of the bushes on campus. Now use your digital camera to take pictures of these plants, and write down their detailed features according to the following instructions.
(The student follows the instructions.)
> Context-aware u-learning system: Now we are going to learn to identify the trees on campus.
…
Case 2: Assessment via identifying real world objects
> **Context-aware u-learning system:** Now we are going to evaluate your knowledge concerning the TYPE of plants. The time limit for the first test item is 15 minutes. Are you ready?
> **Student:** Yes.
> **Context-aware u-learning system:** Find all of the "herbs" on campus and click the "Confirm" button of your learning device when you are in front of the plants.
…
> **Context-aware u-learning system:** The time limit of the second test item is 15 minutes. Are you ready?
> Student: Yes.
> **Context-aware u-learning system:** Find all of the plants with leaves shaped like "needles" and click the "Confirm" button of your learning device when you are in front of the plants.
…
> **Context-aware u-learning system:** Find the plant with the sign "pine" and the plant with the sign "bald cypress". Compare their needle patterns.
…
Case 3: Real world observation with online data searching
> **Context-aware u-learning system:** Now we are going to learn to recognize the plants on campus by identifying their features. Can you see the plant in front of you?
> **Student:** Yes.
> **Context-aware u-learning system:** Do you know the name of this plant?
> **Student:** No.
> **Context-aware u-learning system:** Connect to the plant database, which will help you to recognize the plant. When you are ready to answer this question, click the "Ready" button.
…
Case 4: Cooperative problem solving
(In this case, each cooperative learning group consists of four students who are asked to complete the map of a campus.)
> Context-aware u-learning system: John, now you are in the north-western area of the campus. You can see the locations of your team members on the screen of the learning device. There is a communication window in the top-right-hand corner of the screen that allows you to communicate with them. What you need to do is complete the map of the campus by locating each building and avenue in the correct position.
(John attempts to specify a location for a building.)
> Context-aware u-learning system: The location has been occupied by another building located by Tom. Please check it.

6. Research Issues and Potential Applications

Owing to the context-awareness features, a context-aware u-learning environment is able to conduct more active and more adaptive learning activities in the real world, which makes it quite different from an e-learning or a broad sense u-learning environment. In the meantime, various research issues arise: How can we apply those new parameters extracted from the sensed personal and environmental contexts to improve the learning performance of students? How can a teacher assess the problem-solving abilities of the students in the real world? How can such real-world

learning be integrated with the resources on the Internet? In the following subsections, research issues as well as the potential applications of context-aware u-learning are given.

A. Research Issue

In this subsection, several issues concerning system development, tutoring and assessment strategies, and learning management are proposed:

1. New pedagogical theories for context-aware u-learning environments: New modes of learning will involve new pedagogies. As context-aware u-learning is still in its developmental stage, educational researchers may propose some innovative thoughts about its pedagogy. Perhaps some modifications of existing theories are still feasible for implementing u-learning. For example, some cognitive or learning theories (such as the ideas of situated cognition, Brown, Collins & Duguid, 1989) may be revised and re-examined to interpret student learning in context-aware u-learning).
2. Tutoring strategies for context-aware u-learning: As context-aware u-learning may induce new ways of learning, the tutoring strategies may be revised accordingly. More research should be conducted to explore the teaching effectiveness of different tutoring strategies for various ways of implementing u-learning.
3. Assessment strategies for context-aware u-learning: The assessment is critical and it is a part of teaching. Context-aware u-learning environments will require more alternative ways of assessment. The assessment strategies for situated learning, adaptive learning and cooperative learning involved in context-aware u-learning need more research.
4. Innovative and practical use of ubiquitous technologies for education, learning and training: Researchers are encouraged to implement more innovative use of context-aware u-learning, and explore its potential to complement other forms of instruction. The actual effects of utilizing ubiquitous technologies need more large-scale research.
5. Psychological analysis for context-aware u-learning and training: It is obvious that a better understanding of the psychological factors related to u-learning can help educators or system designers to develop more appropriate learning environments. As context-aware u-learning environments have the capacity to record a variety of each individual learner's personal information, related behaviors and environmental parameters (as a personal electronic portfolio), researchers can use these data to analyze in depth student learning processes and related factors which may facilitate learning.

B. Considerations of actual implementations

In its current stage, the expense of constructing context-aware u-learning systems is still very high. While attempting to employ context-aware u-learning, one might need to take the following considerations into account:

Do the learners need support from the system?
Do they need personalized instructions?
Do the instructions or support need to be given actively?
Do the learners need to move from place to place during the learning process?
Do the learners need to learn in the real world? Is u-learning in the real world better than simulation, e-learning or simple lectures?
Does the context (e.g. location or environmental temperature) of the learner affect the learning process?
Can the system be used in the future for other learners?

If the answers to most of the above questions are "Yes", the educators can consider implementation. In our opinion, subjects such as science (e.g., the observation of plants or animals), oral language practice, physical education, or e-training in some factories may have more potential for the application of u-learning.

7. Conclusions

Although u-learning or context-aware learning environments have attracted the attention of researchers in the fields of computer science and education, the criteria for establishing a fully functional u-learning environment is still

unclear. In this paper, we have attempted to define the basic criteria of a u-learning environment, and propose various models of conducting u-learning activities. It can be recognized that a variety of personal and environmental parameters are available in a u-learning environment, such that more adaptive support can be provided by the system. In addition, the real-world observation and problem-solving abilities of the learner can be trained and evaluated in such a context-aware environment.

Basically, there are several levels of individualized guidance which can be provided in a context-aware u-learning environment: for naive learners, adaptive supports and guidance for real-world operations or observations can be provided; however, for experienced learners with different backgrounds and experiences, only hints or necessary warnings are given.

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