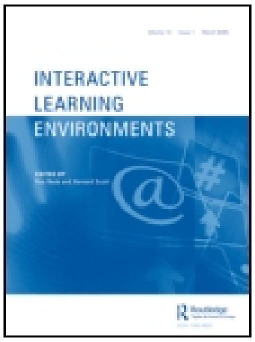

Interactive Learning Environments

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

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To cite this article: Chih-Ming Chen & Yi-Lun Li (2010) Personalised context-aware ubiquitous learning system for supporting effective English vocabulary learning, Interactive Learning Environments, 18:4, 341-364, DOI: 10.1080/10494820802602329

To link to this article: https://doi.org/10.1080/10494820802602329

Published online: 15 Jan 2009.

Interactive Learning Environments
Vol. 18, No. 4, December 2010, 341–364

Routledge
Taylor & Francis Group

Personalised context-aware ubiquitous learning system for supporting effective English vocabulary learning

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(*Received 11 June 2008; final version received 15 October 2008*)

Because learning English is extremely popular in non-native English speaking countries, developing modern assisted-learning schemes that facilitate effective English learning is a critical issue in English-language education. Vocabulary learning is vital within English learning because vocabulary comprises the basic building blocks of English sentences. Therefore, numerous studies have attempted to increase the efficiency and performance of learning English vocabulary. 'The situational learning approach' proposed that 'context' is an important consideration in the language learning process and can enhance learner learning interest and efficiency. Restated, meaningful vocabulary learning occurs only when the learning process is integrated with social, cultural and life contexts. With the rapid development of context-awareness techniques, the development of context-aware mobile learning systems, which can support learners in learning without constraints of time or place via mobile devices and associate learning activities with real learning environment, enables the conduct of a novel context-aware ubiquitous learning mode to enhance English vocabulary learning. Accordingly, this study proposes a personalised context-aware ubiquitous learning system (PCULS) for learning English vocabulary based on learner location as detected by wireless positioning techniques, learning time, individual English vocabulary abilities and leisure time, enabling learners to adapt their learning content to effectively support English vocabulary learning in a school environment. Experimental results indicated that the accuracy of the employed wireless positioning scheme is over 92%, which is sufficient to help learners detect their locations. Additionally, the PCULS has been successfully implemented on PDA devices in a school environment to support effective situational English vocabulary learning. Experimental result indicates that the learning performance of learners who used personalised English vocabulary learning systems with context awareness (i.e. PCULS) was superior to learners who used personalised English vocabulary learning systems without context awareness.

Keywords: context-aware ubiquitous learning; wireless positioning technique; personalised learning; English vocabulary learning

1. Introduction

The rapid development of wireless network technologies has enabled people to conveniently access the Internet from more diverse locations. Wireless local area network

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ISSN 1049-4820 print/ISSN 1744-5191 online

DOI: 10.1080/10494820802602329
http://www.informaworld.com

(WLAN) offers an excellent solution for schools and companies wishing to establish internet infrastructure. Additionally, the pervasiveness of handheld mobile devices, such as Tablet PC, PDA and cell phone, has transformed learning modes from E-learning (electronic learning) to M-learning (mobile learning). Particularly, compared with traditional classroom learning, M-learning overcomes limitations of learning time and space. Recently, the concept of 'context-aware ubiquitous learning' has been further proposed to emphasise the characteristics of learning the 'right content' at the 'right time' and 'right place', and also to facilitate a seamless ubiquitous learning environment that supports learning without constraints of time or place (Ogata & Yano, 2004). The so-called 'context-aware ubiquitous learning' (Rogers et al., 2005; Tummala & Jones, 2005; Wang, 2004; Wilkerson, Griswold, & Simon, 2005) thus requires the detection of learner context information and provides learning with different learning content via mobile devices in response to different learning contexts. Dey (2000) proposed four main types of contextual information, including identity, time, activity and location, for building context-aware applications. To determine learner location, global positioning system (GPS) detects user location where the GPS receiver simultaneously senses a minimum of three satellites in outdoor environments by the triangulation method (Ahmed, 2006). Compared with GPS, WLAN can provide precise location information in both indoor and outdoor environments and has been widely set up in most public or school environments (Kupper, 2005). WLAN positioning is a more suitable method of enabling the development of 'context-aware ubiquitous learning' that can provide learning content associated with learning contexts and assists learners in context-based learning in a campus environment.

Nevertheless, the rapid growth of the internet has shortened the distance between people from different countries, making the world into a global village. English language abilities have become very important, and are now a basic skill in many nations. Therefore, developing an effective learning tool for learning English has become an important issue in English-language education (Collins, 2005; Shih, 2005). English as a foreign language learning requires the support of various learning tools to offer additional opportunities to learn English. Recently, various innovative learning methods have been proposed to support language learning activities, for example mobile English vocabulary learning by PDA (Chen & Chung, 2008; Chen & Hsu, 2008), and some studies have proposed using cell phones to assist language learning (Kiernan & Aizawa, 2004; Collins, 2005).

Among all English-language skills, English vocabulary competence is crucially important and is the foundation of language learning (Beck, McKeown, & Kucan, 2002; Bormuth, 1966; Davis, 1944, 1968). Huckin, Haynes, & Coady (1993) indicated that reading ability and vocabulary knowledge are two key components of second language performance and moreover are mutually dependent, especially in academic settings. Additionally, Stahl & Fairbanks (1986) indicated that knowledge of word meanings is strongly related to reading comprehension skills. Moreover, Wilkins (1972) argued that 'without grammar very little can be conveyed, and without vocabulary nothing can be conveyed'. Recently, numerous studies have investigated learning English, and have particularly emphasised the importance of vocabulary learning (Chen & Chung, 2008; DeCarrico, 2001; Lewis, 1993; McCarthy, 1984; Meara, 1980). Excellent vocabulary abilities are beneficial in inferring meaning from English sentences (Harmon, 1998; Rupley, Logan, & Nichols, 1999). The English language education field thus should pay more attention to developing innovative English vocabulary learning tools.

'The situational learning approach' (Hornby, 1950) proposed that 'context' is an important factor in language learning, capable of enhancing learning interest and efficiency. Meaningful knowledge is constructed only when process of learning integrates with cultural and life contexts. Assimilating knowledge in a real world environment shortens learning time and enhances learning efficiency. Moreover, learners who actively interact with the real word can apply this authentic and social knowledge to the everyday environment that surrounds them. Pestalozzi, an 18th Century philosopher, advocated the principle of Anschauung – direct concrete observation (Silber, 1965). Pestalozzi emphasised sensory experiences and encouraged the entry of natural science and geography. He frequently took children to explore the surrounding countryside, and especially to observe the local natural environment and topography. The children would examine the minerals, plants and animals they encountered in the real environment, and then developed ideas based on their sensory impressions. Thus, exploring the real world and surrounding contexts benefits language learning. Miller & Gildea (1987) also indicated that learning vocabulary is an everyday practice, and using a sample of learners with an average age of 17 years, they demonstrated that learners learn vocabulary at a rate of about 13 words per day. If vocabulary learning is meaningful to learners, they will naturally understand the meaning and usage of the words learned. Generally, learning English vocabulary from abstract definitions in the dictionary is slow and less successful. More importantly, dictionary-based learning leads to problems when using language in real world situations (Brown, Collins, & Duguid, 1989).

On the basis of the situational learning approach and contextual information in the context-aware computational method proposed by Dey (2000), a 'personalised context-aware ubiquitous learning system (PCULS)' based on considering four types of context-aware information, including learner location, current learning time, learner vocabulary ability and leisure time available to the learner is proposed to improve the English vocabulary learning of individual learners in this study. The proposed system uses an existing WLAN infrastructure to gather assess point (AP) signal strength information and detect location based on back-propagation neural networks. Additionally, item response theory (IRT) (Baker & Frank, 1992; Hambleton & Swaminathan, 1985; Hambleton, Swaminathan, & Rogers, 1991; Hulin, Drasgow, & Parsons, 1983) and a fuzzy inference mechanism (Lin & George Lee, 1996) were respectively employed to evaluate learner vocabulary ability and how many vocabulary items were learned based on immediate test responses and leisure time of individual learners during learning processes. Experimental results demonstrate that utilising context-awareness techniques tailored to the learning environment and content to memorise English vocabulary via mobile devices can reliably enhance English vocabulary ability. The effectiveness of this technique stems from the fact that context-aware ubiquitous learning facilitates learning activities by providing the 'right content' at the 'right time' and 'right place', and is a convenient method for seamless ubiquitous English learning without constraints of time or place by mobile devices.

2. System design

This section describes the proposed system architecture, positioning methodology and vocabulary recommendation mechanism. The architecture of the proposed system is explained in Section 2.1, and the proposed WLAN positioning approach is detailed in Section 2.2. Finally, the recommendation mechanism for determining suitable vocabularies for individual learners based on context-awareness is described in Section 2.3.

2.1. System architecture

In this study, the PCULS is proposed and it depends on learner location, learning time, leisure time and personal vocabulary ability to provide adaptive English vocabulary learning. The proposed system aims to enhance learner impressions and interest in relation to learning English vocabulary, and also to boost the performance of English vocabulary learning based on the situational learning approach supported by WLAN positioning techniques. Figure 1 illustrates the system architecture.

2.1.1. System components

The proposed learning system is composed of the client side, data synchronised agent and server side. The left part of Figure 1 presents the system architecture of the client side. The client side, which comprises six intelligent agents and three databases, attempts to recommend new words to individual learners based on the proposed context-aware scheme for personalised English vocabulary learning. The right part of Figure 1 shows the server side system architecture. The server side, which contains two databases, one data management interface, and one English courseware classification agent, is responsible for collecting English vocabulary from web sites that contain required English course materials and providing a user-friendly interface for managing vocabulary by an administrator (i.e. an instructor). To support off-line learning, the data synchronised

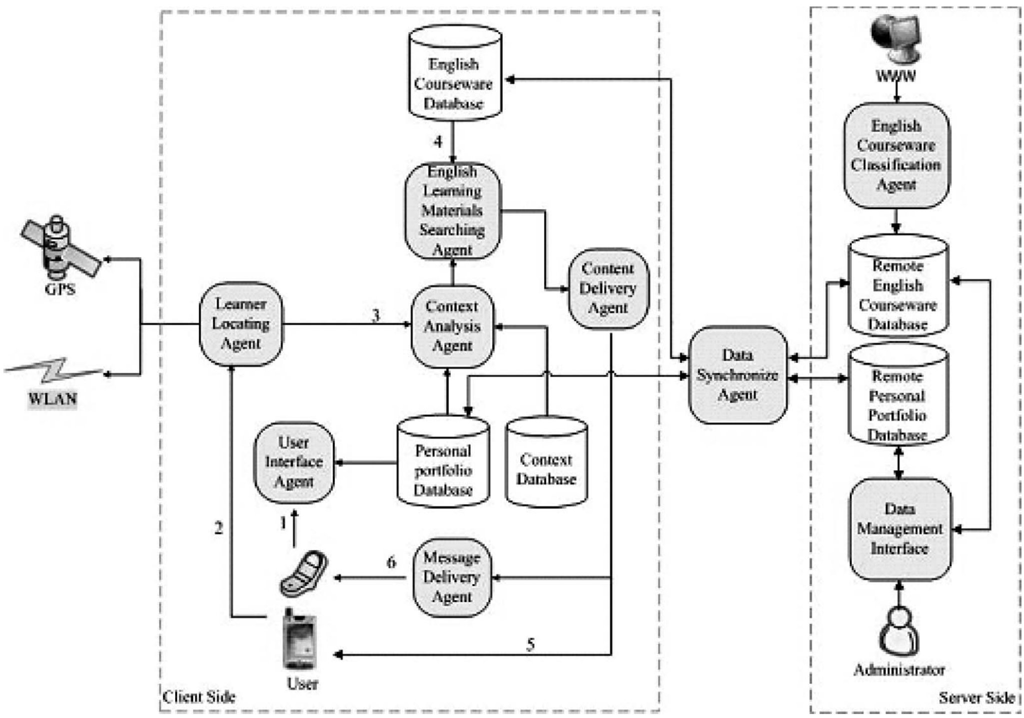


Figure 1. The system architecture of personalised context-aware ubiquitous learning system for learning English vocabulary.

agent is responsible for maintaining data consistency between the client and server databases following the wireless network connecting. The functionality of each intelligent agent within the system is detailed below.

(1) The client side
  (a) The learner locating agent
  The agent attempts to detect the learner's location and can assist to choose different vocabularies depending on individual learner location. This study employed WLAN positioning techniques in a schoolyard environment to sense learner location.
  (b) The user interface agent
  Learners can log into the learning system and decide to learn or review English vocabulary through the user interface agent. The user interface agent can also display individual learner learning states to improve understanding of individual vocabulary ability. This agent is also responsible for interacting with the user account database to confirm learner identity.
  (c) The context analysis agent
  On the basis of a learner's location, this agent cooperates with both the personal portfolio and context databases to determine the learning parameters associated with the context.
  (d) English learning materials searching agent
  Suitable English learning materials that are related to the context of the sensing learner are discovered from the English courseware database based on the analytical results obtained by the context analysis agent.
  (e) The content delivery agent
  This agent organises the English materials discovered by the English learning material searching agent into the right style of learning content that fits the learner's mobile device, then transmits these learning materials to the learner who is learning English vocabulary via PDA or cell phone.
  (f) The message delivery agent
  If a learner is learning English vocabulary through a cell phone, the system will send learning content that matches the learner's ability and context in the form of short messages to the learner. For PDAs, the full learning content will be sent to the PDA.
  (g) The English courseware database
  The English courseware database comprises English materials to support English vocabulary learning.
  (h) The personal portfolio database
  The personal portfolio database contains personal information, including learning statuses, and the English vocabulary abilities of individual learners.
  (i) The context database
  The context database contains the corresponding contextual information for each piece of English vocabulary as well as the location on the campus where the learning takes place, and this information is used to support the analysis of the context analysis agent.
(2) The server side
  (a) The English courseware classification agent
  Through information retrieval techniques, this agent automatically retrieves courseware from the web site with needed English course materials. Then it

stores and classifies the course materials according to courseware difficulties and context attributes by human assistance.

(b) The data management interface
An administrator can add, modify or delete learning content, and assess the learning states of individual learners through the data management interface.

(c) The remote English courseware database
The remote English courseware database comprises English vocabulary materials from the vocabulary collection of the Taiwan GEPT general English proficiency test (GEPT). These English vocabulary materials consist of three different GEPT grading levels: elementary, intermediate and high-intermediate. The gathered GEPT vocabulary was used for English vocabulary learning by tenth grade high school students in this study.

(d) The remote personal portfolio database
Personal information, including individual learner learning status and English abilities, is stored in the remote personal portfolio database and the administrator can monitor learner learning activities and provide assistance as appropriate. The remote personal portfolio database maintains data consistency with the databases on the client side using the synchronised agent.

(3) The data synchronised agent
To support off-line learning, the data synchronised agent oversees the task of maintaining data consistency between the client and server databases following the wireless network recovers on-line connection. In this study, the merger replication technique provided in Microsoft SQL server was employed to perform this task.

2.1.2. *System operation procedure*

On the basis of the system architecture, the details of the client side system operating procedure are described and summarised below:

Step 1: A learner logs in to the proposed PCULS through the user interface. As the learner logs in to the system, the user interface agent checks the individual learner account stored in the user account database and also checks the leisure time available for English vocabulary learning. Meanwhile, the setting information is stored in the personal portfolio database.

Step 2: After the learner logs in the system, the learner locating agent automatically senses the learner location by the proposed neural-network-based WLAN positioning techniques.

Step 3 and 4: On the basis of the location of the learner, the context analysis agent retrieves the context information from the personal portfolio and context databases. Consequently, the English learning material searching agent discovers the proper English vocabulary materials that fit the learner context according to the analytical results of the context analysis agent.

Step 5: The content delivery agent organises the English learning materials discovered by the English learning material searching agent as the appropriate form of content, and transmits them to the learner's device.

Step 6: The message delivery agent transmits the learning contents in the form of a web page to the learner's PDA or in the form of short message to the learner's cell phone. The user then returns to **Step 2** to perform the next learning cycle or logs out, terminating the learning process.

2.2. WLAN positioning methodology

Detecting the location context is an important function in this study. After analysing the advantages and disadvantages of several positioning techniques and considering the limitations of real world environments, this study employed the neural-network-based WLAN positioning technique to develop a positioning service based on the wireless network existing in a schoolyard, because WLAN has been widely installed in most schoolyards to provide wireless internet services. Compared with the RFID, infrared and ultrasound positioning techniques (Kupper, 2005), WLAN has the lowest positioning infrastructure costs. Furthermore, this study employed a back-propagation neural network, a machine learning technique, to induce the mapping relationships of the collected signal strength information with learner location. Subsequently, the trained back-propagation neural networks were used to predict learner positions in accordance with the positioning inducing knowledge. The following subsections first introduce the employed back-propagation neural networks and their applications. Finally, the procedures used to detect learner location are detailed.

2.2.1. *The employed back-propagation neural networks*

The back-propagation neural network is an artificial neuron computing system (Lin & George Lee, 1996). Much like the human brain, a neural network is composed of interconnected nodes and directed links with corresponding weight information. Among the proposed neural network learning models, a back-propagation neural network is the most widely used in practice and it is well known for its high accuracy, good generalisation ability and rapid recall process. This study used the back-propagation neural network model to classify signal strength features into corresponding locations. A back-propagation neural network is a supervised model and includes both learning and recall phases. In the learning phase, the model learns how to map the input data to the corresponding output data, and also determines the weights of the network connections. The induced weights are then used to compute the output newly arrived data for prediction purposes. A typical back-propagation neural network architecture consists of input, hidden and output layers. Each layer receives the output of the precedent layer as an input. The architecture of the neural network with a single hidden layer was used in this study. The signal strength of each AP serves as the input feature of each neural node in the input layer, and the outputs represent the corresponding locations.

2.2.2. *Location detection*

This study utilises indoor WLAN to estimate learner location. By measuring the signal strengths emitted by each AP, the location is used to infer learner context. The location detection involves two stages, as described below.

- The first stage (off-line phase)
  To establish the radio map database, plenty of signal strength samples were gathered to construct a neural network classifier model for inferring signal strengths into corresponding geographic locations. Each record represents the signal strength values emitted from n APs and their corresponding locations, and can be stored using the following format: $\{SS_1, SS_2, SS_3, SS_4, \ldots, SS_n, Location\}$. During the data collection, some locations may have weak or even no signals because of long

distances between the mobile side and the APs, or blocks of walls. Because the signal strength ranged from -30 dBm to -100 dBm, the signal strength value was assigned to -100 dBm for the location where no signal strength was detected.

- The second stage (on-line phase)
  The back-propagation neural network model established during the first stage is implemented and installed on the learner mobile side (PDA). When a learner initiates the positioning service, the trained neural network model implemented in the learner locating agent immediately identifies the location of the learner according to the signal features detected by the learner's mobile device.

2.3. Recommending context-aware English vocabulary and testing sheet

The system learning process comprises learning new English vocabulary and testing learners on their recently learned vocabularies. First, the context analysis agent is in charge of recommending context-based English vocabulary to individual learners based on four aspects of context information including learner vocabulary ability, learning location, current learning time and free time available to the learner. A test sheet related to the learned vocabulary is then generated to assess learning performance and re-evaluate the English vocabulary ability of the learner. The detailed procedures on the process of recommending context-aware English vocabulary are explained below. First, the proposed English vocabulary recommendation mechanism selects English vocabulary associated with learner location from the English courseware database for further consideration of whether this vocabulary is suited to the learner's English vocabulary ability and matches their free time availability characteristics. Next, the information function values of the selected vocabularies in the previous step are estimated based on individual learner vocabulary ability. These were applied to identify appropriate English vocabularies for individual learner learning. Meanwhile, these selected vocabularies were also assessed in terms of their time characteristic scores based on learner learning time. A linear combination approach with an adjustable weight was applied to integrate the information function value with the time characteristics score to derive a final score for determining appropriate vocabularies for individual learner learning. In this study, all selected vocabularies associated with learner location were ranked according to final scores. Finally, the proposed system recommends vocabulary based on the ranking order of final scores. Moreover, the recommended size of the learning vocabularies is inferred based on individual learner ability and leisure time. That is if the estimated amount of learning vocabulary is K, then the vocabularies with top K high final scores are recommended to individual learners for vocabulary learning. The following subsections explain this vocabulary recommendation strategy in detail.

2.3.1. Selecting location-based English vocabulary

Location information is the main factor in context-aware or context-based systems. According to the situational learning approach, this study first focussed on recommending English vocabulary related to current learner location to individual learners. For instance, some words, such as exam, student and assess, are appropriate to be learned if the learner performs the learning process in a classroom, whereas other words, such as baseball, jump and athletic, were appropriate for learners in a sports ground environment. Therefore, the first step in vocabulary recommendation is to select English vocabulary based on learner location. Next, the selected English vocabularies associated with current learner location are ranked to determine appropriate vocabularies for individual learners based on a weighted linear combination of the information function values and time characteristics scores. The following subsection demonstrates how to decide appropriate vocabulary for individual learners based on their existing English vocabulary ability using the information function in IRT.

2.3.2. Evaluating English vocabulary ability and recommending English vocabulary based on information function

IRT (Baker & Frank, 1992; Hambleton & Swaminathan, 1985; Hambleton, Swaminathan, & Rogers, 1991; Hulin et al., 1983) is a widely used theory in education measurement, typically applied in the field of computerised adaptive testing (CAT) (Horward, 1990; Hsu & Sadock, 1985) to select the most suitable items for examinees based on individual abilities. The CAT efficiently reduces test time and number of testing items, and can precisely estimate examinee abilities. The concept of CAT is applied to replace conventional measurement instruments (which are typically fixed-length, fixed-content and paper-pencil tests) in several real-world applications such as the test of English as a foreign language (TOEFL) (http://www.toefl.org), graduate record examinations (GRE) (http://www.gre.org) and graduate management admission test (GMAT) (http://www.gmat.org). In this study, IRT was applied to assess learner vocabulary ability for the proposed PCULS for personalised learning services.

To estimate a learner's English vocabulary ability, the item characteristic function with a single difficulty parameter proposed in IRT (Baker & Frank, 1992; Hambleton & Swaminathan, 1985; Hulin et al., 1983) is used to model each vocabulary word. In the proposed system, learner vocabulary abilities are limited between -3 and $+3$. That is, learners with $\theta = -3$ have the poorest ability, those with $\theta = 0$ have moderate abilities and those with $\theta = +3$ have the best abilities. This system estimates learner vocabulary ability based on learner test responses. If a learner memorises the recommended vocabulary words and provides correct test responses, then a learner's vocabulary ability will be promoted based on the IRT estimated formula for learner ability; otherwise, learner vocabulary ability will be descended.

Two approaches in IRT are commonly used to evaluate appropriate vocabulary words to individual learners – the information function strategy and Bayesian strategy (Baker & Frank, 1992; Hambleton & Swaminathan, 1985; Hulin et al., 1983). The information function method was applied to estimate appropriate vocabularies for individual learners. The information function is defined as:

$$I_j(\theta) = \frac{(1.7)^2}{\left[e^{1.7(\theta - b_j)}\right]\left[1 + e^{-1.7(\theta - b_j)}\right]^2} \tag{1}$$

where $I_j(\theta)$ is the information value of the jth vocabulary at a level below their ability level θ and b_j is the difficulty parameter of the jth vocabulary.

2.3.3. Evaluating the score of time characteristic of vocabulary

After calculating the corresponding information function value of each vocabulary, the time characteristics of all selected location-based English vocabularies are also considered for use in calculating the time characteristic scores to further integrate with the information function values of vocabularies. The determination of time characteristic scores for vocabulary is designed to identify the English vocabulary associated with learning time when learners conduct learning activities. For example, certain vocabulary items, such as sleep, star and dark, are suitable for learning at night because they are associated with night time. Furthermore, other words, such as cold and snow, should be presented to learners during winter because they are generally associated with this season. Thus, the context analysis agent can monitor learning time and evaluate vocabulary items within the system to seek matches with the current learning time, season or festival. When people discuss the beginning or end of specific times or reasons, different time or seasons have different time measures involving hour, week or month. For example, when discussing the afternoon, it can be said to refer to the period from 1:00 pm to 5:30 pm, in which case the relevant unit of time measurement is hours. Moreover, when talking about spring, people may think of the time measure as month and define spring as running from February to April.

Furthermore, different festivals have different beginning and end ranges. For example, the Chinese New Year is a major celebration for Chinese people, with the celebratory atmosphere lasting 2 weeks or more. A comparable western festival is Christmas, which sees associated symbols such as Christmas trees, cards, wreaths and so on appear a month or more in advance of December 25th. Compared with Chinese New Year and Christmas, a celebration such as teacher's day is rather small scale and involves a much shorter time period.

Thus, based on the above properties, fuzzy theory (Lin & George Lee, 1996) is suitable for describing the characteristics of different times. Therefore, the score of time characteristic is computed based on fuzzy inference in this study. Additionally, the vocabularies stored in the English courseware database were manually classified into different situational categories based on various time characteristics in advance. The fuzzy membership functions for each time characteristic are heuristically determined in this study. Figure 2a,b illustrates two examples of fuzzy membership functions used for the time characteristics of winter and Christmas.

Following the score of time characteristic of the jth English vocabulary denoted as TC_j and the information function value denoted as I_j are decided, the final score S_j of the jth English vocabulary can be measured using the following weighted linear combination function:

$$S_j = w \times I_{j(n)}(\theta) + (1 - w) \times TC_j \tag{2}$$

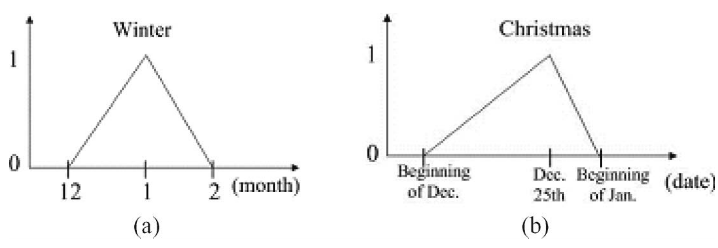


Figure 2. The defined fuzzy membership functions for different vocabularies with time characteristic. (a) The fuzzy membership function for winter. (b) The fuzzy membership function for Christmas.

where w is an adjustable weighting factor reflecting the relative importance of learner ability and the time characteristic, TC_j is the time characteristics score of the jth English vocabulary, $I_{j(n)}(\theta)$ represents the normalised information value of the jth vocabulary at a level below their ability level θ, and the range of $I_{j(n)}(\theta)$ is between 0 to and 1.

After calculating the corresponding final score of vocabulary, vocabularies with higher final scores are delivered first to individual learners. The following section discusses the quantity of vocabulary that should be delivered to individual learners based on learner leisure time.

2.3.4. *Estimating the amount of learning words*

Learners wishing to learn new vocabulary may differ in the free time they have available to do so. Learners may sometimes have very short periods of leisure time, such as when they are waiting for a few minutes for a friend to arrive. At other times learners may have much more time, such as after class. Hence, the quantity of recommended vocabulary to be learned should adapt to differences in the leisure time available to individual learners, to enable them to maximise their limited available time for learning. The context analysis agent decides the amount of learning vocabularies based on learner ability and available free time using pre-designed fuzzy rules. If a learner has achieved a relatively high English vocabulary ability as a result of learning, the learning system will recommend more difficult English vocabularies. In contrast, learners with lower English vocabulary abilities will be given easier vocabulary to learn. Under the same leisure time, learners with high English vocabulary ability require more time to memorise more difficult vocabularies than do learners with moderate English vocabulary ability. Thus, learners with higher English vocabulary ability will be recommended less vocabulary than those with moderate English vocabulary ability to encourage them to completely memorise the recommended vocabulary during their leisure time. Before performing learning, the learner is asked to select a value between -1 and 1 to indicate the amount of free time they have available.

Besides, a defuzzification process was employed to infer learning vocabulary number based on the designed fuzzy rule base via fuzzy inference. In the fuzzy set theory, the centre of gravity (Lin & George Lee, 1996), which is the most widely used defuzzification scheme, calculates the crisp values of learning vocabulary number from the most typical values and respective degrees of membership function. If the estimated size of learning vocabularies is K, the system will deliver the top K English vocabularies to the learner according to the ranking order of the final scores.

3. Experiments

Section 3.1 first describes the positioning experiment to verify whether the accuracy rate of WLAN positioning scheme satisfies the requirement supporting context-aware learning. Section 3.2 demonstrates the implemented PCULS for learning English vocabulary in this study. Finally, Section 3.3 evaluates the learning effectiveness of the proposed personalised context-aware ubiquitous English vocabulary learning system. In this work, a non-equivalent pre- and post-test group based on the quasi-experimental design was designed to conduct learning activity and 36 tenth grade students in the affiliated high school of National Chengchi University (http://www.ahs.nccu.edu.tw/) were invited to participate in this experiment during 2 weeks.

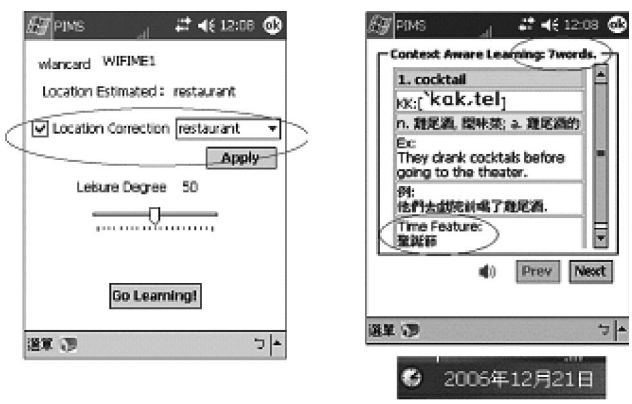
3.1. WLAN positioning experiment

To collect signal strength features for training the employed back-propagation neural networks is the most important work affecting positioning learner location in the proposed English vocabulary system. However, for some reasons, such as multi-path and refraction, the signal therefore generates irregular fluctuation and becomes as noisy data. Therefore, it is essential to apply noisy data filtering mechanism to eliminate noisy training data. The noisy data filtering mechanism proposed in this study is based on the concepts of mean and bias in the statistics analysis. Once the better training data is generated after filtering out noisy data, the learning effect of neural network can be obviously promoted. Furthermore, merely sensing signal strength features once from each AP may simply reflect noise and result in incorrect location decision. To reduce interference from signal fluctuation and improve the accuracy of position prediction, the signal strength features are measured more than once and supplied before the positioning estimation in this study. In the estimations, the area label with the largest number of appearances serves as the final positioning result. The experimental results demonstrate that overall accuracy increases when the value of the sampling parameter increases from three to eight. The best location accuracy of 92.7% occurs when the sampling parameter is set to 8, and is enough to aid the location detection of learner. However, how to determine the optimal sampling parameter for WLAN positioning requires further investigation.

3.2. The implemented PCULS on PDA supported by a courseware management server

This section details PCULS implemented by the platform of Microsoft Visual Studio.Net 2003. Currently, the client mobile learning system is implemented on the PDA with the operating system of Windows mobile 2003 and the database of Microsoft SQL Server CE edition 2.0. Moreover, the remote courseware management server is implemented on the Microsoft Windows 2000 Server with Microsoft SQL Server 2000 database.

Figure 3a shows the functionalities for identifying the learner's location, adjusting the current leisure degree for inferring appropriate number of vocabularies for learning and



(a) (b)

Figure 3. The implemented personalised context-aware ubiquitous learning system for learning English vocabulary. (a) The functionalities of location detection, leisure time adjustment and location correction. (b) The learning vocabulary at restaurant on December 21.

correcting location information. That is, learners can correct location by the interactive interface with prior building location information if the PCULS has incorrect learner's location detection. After the learner selects to continue the learning process, the context analysis agent and English learning material searching agent will find out suitable vocabularies to the learner according to the learner's ability, leisure degree, current location and current learning time. Figure 3b shows the recommended English vocabulary and the number of learning vocabularies decided by the context analysis agent. Meanwhile, learners can click on the trumpet-shaped button to listen the pronunciation of the selected vocabulary for training listening ability. Figure 3b also displays the system can recommend appropriate vocabulary to individual learners according to different learning time. In Figure 3b, the vocabularies with the characteristic of Christmas have higher priorities to be recommended to the learner because the learning time is close to 25th December. Additionally, the learning statuses of each learner will be sent to the courseware management server and stored in the personal portfolio database. The courseware management server provides a user-friendly interface for teachers to inspect the learners' learning portfolios to further understand the learning performance of individual learners.

3.3. Experimental design and analysis

3.3.1. Experimental design

To evaluate the learning performance of the exploratory PCULS for learning English vocabulary, 36 tenth grade students studying in the affiliated high school of National Chengchi University were invited to participate in this experiment. The students were randomly assigned to either the experimental or control groups. Each group contained 18 students with the average age being around 16 years old. Each group contained nine males and nine females. A non-equivalent pre-test and post-test group based on a quasi-experimental design was employed to analyse the learning performance of the proposed system. Table 1 lists the experimental design of both the experimental and control groups.

Before performing the experiment, all participants received a 100 min training course in operating their PDAs and using the implemented English vocabulary learning system with or without context-aware service. In this experiment, the experimental group learned the recommended vocabulary with the support of the proposed context-aware service, whereas the control group learned the same vocabulary without such support. The vocabulary learning activity of two groups lasted 2 weeks. Both the learning modes took the pre-test and post-test for comparing the difference in learning performance before and after learning using PDA. To provide a context-aware service for English vocabulary

Table 1. The experimental design for assessing learning performance.

Group	PDA operation training	Pre-test	Learning process (2 weeks)	Post-test	Number of learners	Female	Male
Experimental group	✓	✓	Vocabulary learning with context aware service	✓	18	9	9
Control group	✓	✓	Vocabulary learning without context aware service	✓	18	9	9

learning in the experimental schoolyard, 12 campus locations in the affiliated high school of National Chengchi University were chosen to provide a location-based context-aware service. Table 2 lists the selected locations for the context-aware service. The students of the experimental group were free to go to these places at anytime and the proposed system could recommend suitable English vocabulary related to learning environment to individual learners for English vocabulary learning. Figure 4 illustrates the learning scenario of the experimental group students who learned English vocabulary via the proposed personalised vocabulary learning system with context-aware service in the garden.

To assess learning performance, two parallel versions of the testing sheet were constructed by an experienced English teacher at the affiliated high school of National Chengchi University for both the pre-test and post-test, and were used respectively to measure student English vocabulary abilities before and after performing the learning process. Each testing sheet contained 20 multiple-choice items and 20 cloze questions selected equally from among three vocabulary levels of GEPT in Taiwan. Another 40 tenth grade students, excluding students in the experimental and control groups, were invited to participate in the tests before the experiment was conducted, and the test results were submitted for item analysis to measure whether the difficulties of both the pre-test and post-test sheets are identical. The analytical results show that the Kuder-Richardson reliability coefficients for both the pre-test and post-test sheets are 0.66 and 0.80, respectively, meaning both testing sheets have consistent reliability. Moreover, the Pearson Product-Moment correlation coefficient of both the test sheets is 0.70, and thus both testing sheets are confirmed to have similar levels of difficulty.

Table 2. The selected locations for English vocabulary learning in the schoolyard of the affiliated high school of National Chengchi University.

Military classroom	Clinic centre	Garden
Computer classroom	Restaurant	Gym
Meeting room	Art classroom	Library
English classroom	Music classroom	Chemistry laboratory

Figure 4. Vocabulary learning in the garden using the proposed system.

3.3.2. Experimental analysis

3.3.2.1. Learning performance analysis. Figure 5a,b displays the learning performance of two participating groups in both the pre-test and post-test. The results show that the percentages of learners with improved scores in both the experimental and control groups are 94 and 67%, respectively. The scores of both the groups improved, but the score increase of the experimental group is superior to the control group. Before performing the PDA learning process for English vocabulary learning, the mean pre-score of the experimental group is 10.39 and the standard deviation is 3.032. The mean pre-score of the control group is 12.61 and the standard deviation is 5.315. After performing the PDA learning process, the mean post-score of the experimental group is 15.61 and the standard deviation is 4.258. The mean post-score of the control group is 14.56 and the standard deviation is 4.973.

To investigate whether there are significant differences in score progress between both the experimental and control groups, an analysis of covariance (ANCOVA) was used to analyse the collected pre-test and post-test data. The first step is to analyse the homogeneity of regression coefficients. The F test result ($F = 0.438$, sig of $F = 0.513$) does not reach the significant level, thus it means the regression slope of two groups is equivalent. This result confirms the assumption of homogeneity of coefficients, and so this study further preceded the ANCOVA. The ANCOVA result reaches the significant level

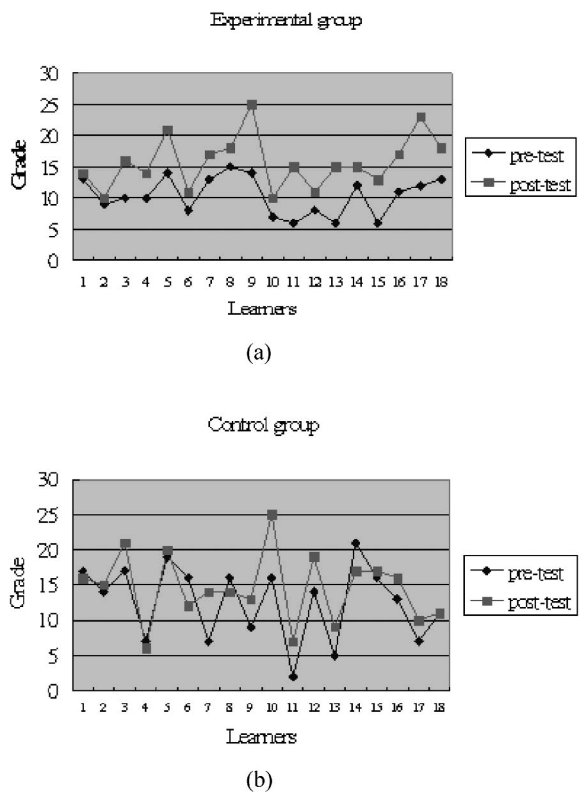


Figure 5. The learning performance of two participating groups. (a) The learners' learning performance in the experimental group. (b) The learners' learning performance in the control group.

($F = 5.785$, sig of $F = 0.022$) after adjusting the dependent effect (group) with respect to the covariance (pre-test). This result indicates that the post-test of two groups has significantly different. Table 3 displays the estimated score of post-test after removing the effect of covariance and this study found that the post-test score of the experimental group is higher than that of the control group. The result shows that the learners who used the proposed vocabulary learning system with context-aware service had better learning performance than the learners who used the vocabulary learning system without context-aware service.

Moreover, in the experimental group, the difference of the mean scores between pre-test and post-test is -5.22 and the paired-samples *t*-test result reaches the significant level. In other words, after performing the proposed learning process, the increase in performance in the experimental group is significant and the mean testing score increases 5.22 points. Similarly, the increase of learners' learning performances is also significant, and the mean testing score increases 1.95 points in the control group. Hence, these two groups significantly made progress whether using the personalised English vocabulary learning system with or without context-aware service for English vocabulary learning. However, the increase of the testing score in the experimental group (5.22) is higher than that in the control group (1.95). On the basis of the results of ANCOVA and paired-samples *t*-test, this study confirmed that the learning performance of learners who used personalised English vocabulary learning system with context-aware service is superior to the learners who used personalised English vocabulary learning system without context-aware service.

3.3.2.2. Questionnaire analysis. To assess learner satisfaction degree for the proposed PCULS, a questionnaire involving 23 questions dealing with four areas was designed to measure whether the proposed system satisfies the requirements of most learners. The four question types contain personal information relating to learner learning by PDA, the convenience of system operation, the investigation of learner learning attitude towards using the proposed learning system and the self assessment of learners' English vocabulary abilities before and after using the proposed PCULS for learning English vocabulary. Eighteen learners in the experimental group were invited to complete this questionnaire after attending the 2 weeks' learning activity.

Table 4 lists the results of satisfaction evaluation. Table 4 (*the investigation results of the personal information*) displays the investigation results of the personal information. To simplify the analytical results, the responses 'strongly agree' and 'agree' are merged into the single response of 'approved', and the responses of 'strongly disagree' and 'disagree' are merged into the single response of 'disapprove'. The evaluation results indicate that the

Table 3. The estimated score of two groups after adjusting the dependent effect with respect to the covariance.

Class	Mean	Std. error	95% Confidence interval: Lower bound	95% Confidence interval: Upper bound
Control group	13.711*	0.793	12.097	15.326
Experimental group	16.455*	0.793	14.841	18.069

Dependent variable: post-test.

*Covariates appearing in the model are evaluated at the following values: pretest = 11.50.

Table 4. The satisfaction evaluation results of questionnaire.

The investigation results of the learning attitude

Question type	Question	The number of learners: Yes	No
Personal information about using PDA	Do you or your family have PDA or mobile phone with PDA?	3	15
	Do you use PDA first time?	13	5
	Have you ever used PDA for learning?	3	15

The investigation results of the system operation

Question type	Question	Satisfaction degree (%): Strongly disagreed	Disagreed	No opinion	Agreed	Strongly agreed
System operation	I think that the proposed context-aware ubiquitous English vocabulary learning system provides a friendly user interface.	0	0	27.8	44.4	27.8
	I am very clear about the learning procedure of the proposed context-aware ubiquitous English vocabulary learning system.	0	0	11.1	72.2	16.7
	I agree that applying location-based context-aware technique in the leaning is novel and it can assist my learning.	0	5.6	50	22.2	22.2
	I agree that the English vocabulary materials presented on the PDA are very clear.	0	17	38.9	44.4	0
	I agree that the vocabularies recommended by the system are highly relevant with my learning location and learning time.	0	5.6	61.1	27.8	5.56
	I think the proposed context-aware ubiquitous English vocabulary learning system is a useful learning tool to assist English vocabulary learning.	0	5.6	38.9	33.3	22.2
	I agree that learning English vocabulary by PDA is very convenient; because I can perform English learning at any time and place.	17	5.6	27.7	27.8	22.2
	The proposed context-aware ubiquitous English vocabulary learning system can effectively assist my learning.	5.6	5.6	44.4	38.9	5.56
	If there are similar English curriculums in the future, I am pleasure to use the proposed system to learn English once again.	5.6	11	22.2	38.9	22.2
	Average	9.4		35.7	54.9	

(*continued*)

Table 4. (*Continued*).

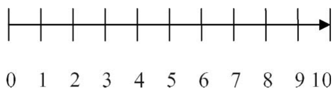
The investigation results of the learning attitude

Question type	Question	Satisfaction degree (%)				
		Strongly disagreed	Disagreed	No opinion	Agreed	Strongly agreed
Learning attitude	The design learning materials on the proposed context-aware ubiquitous English vocabulary learning system can promote my learning interests.	0	11	44.4	33.3	11.1
	I often increase my learning time because learning by the proposed context-aware ubiquitous English vocabulary learning system promotes my learning interest.	5.6	5.6	38.9	38.9	11.1
	I think that using the proposed context-aware ubiquitous English vocabulary learning system can effectively promote my English vocabulary ability.	5.6	5.6	27.8	50	11.1
	I agree that using PDA to learn English vocabulary is a very interesting learning mode.	0	17	22.2	44.4	16.7
	The pronunciation of English vocabulary provided in the proposed system can help me deepen the memorised impression on vocabulary.	0	11	33.3	33.3	22.2
	I think that the integrating English vocabulary learning with the real learning environment is beneficial to my English vocabulary learning.	0	0	38.9	38.9	22.2
	After learning some vocabulary, a cloze test immediately given from the proposed system for the learned vocabulary is very helpful to vocabulary learning.	0	0	27.8	55.6	16.7
	The learning activity offered by the proposed context-aware ubiquitous English vocabulary learning system is more diversified than that of the traditional classroom English vocabulary learning.	0	11	38.9	33.3	16.7
	The proposed context-aware ubiquitous English vocabulary learning system satisfies user-oriented design.	5.6	11	33.3	44.4	5.56
	Compare to the traditional vocabulary instruction, learning English vocabulary based on the learning location and learning time is helpful to promote my linking and memorisation on vocabulary.	0	11	33.3	38.9	16.7
	Average	10		33.8	56.1	

(*continued*)

Table 4. (*Continued*).

The investigation results of the self-assessment

Question type	Question	Vocabulary ability		
		Learner Number	Before learning	After learning
Self assessment	This question aims at self-assessing your vocabulary ability. Please use the notations Δ and ○ to indicate your vocabulary abilities based on the following ability scale before and after using this mobile English vocabulary learning system, respectively. 	1	2	4
		2	2	3
		3	3	5
		4	5	6
		5	4.5	6.5
		6	6.2	7.8
		7	5	6
		8	3.5	4
		9	5.5	5.5
		10	4	7
		11	5.5	6.5
		12	3	5
		13	4	4.5
		14	4	7
		15	2	5
		16	5	6
		17	5	5.5
		18	0.4	0.6
		Average	3.867	5.272

satisfaction degree of 'approved' achieves 54.9% in terms of system operation and 56.1% with regard to learning attitude, as listed in Table 4 (*the investigation results of the system operation* and *the investigation results of the learning attitude*). Moreover, in terms of self-inspection, 17 of 18 learners thought that their vocabulary abilities promoted after using the proposed system for English vocabulary learning, with just one learner not agreeing that their vocabulary abilities improved, and no learners believing that their vocabulary abilities had deteriorated. Table 4 (*the investigation results of the self-assessment*) lists the self-assessment results. The self-assessment results are then submitted to analyse whether learner English vocabulary abilities differ before and after performing learning activity. The analytical results reveal that learner self-assessments improved significantly after using the proposed system ($t = -6.188$, sig of $t = 0.000 < 0.05$). This indicates that most learners agreed that their English vocabulary abilities were enhanced after using the proposed PCULS for learning English vocabulary.

Additionally, to further investigate whether learners significantly prefer the context-aware learning mode provided in the experimental group to the non-context-aware learning mode in the control group, all students in the control group were invited to use the proposed PCULS for 1 week after finishing their learning activity and post-test. That is the 18 students simultaneously experienced both the learning modes (i.e. without and with context-aware service), and then a questionnaire was designed to measure learners prefer which learning mode. Table 5 summarises the questionnaire result. Among the 18 students investigated by the study, this study found that 72.2% of learners preferred to use the proposed PCULS for learning English vocabulary. Meanwhile, 94.4% of learners agreed that using the proposed system with context-aware service could promote their learning motivation. More importantly, all students thought that the proposed PCULS could help them develop a deeper impression of vocabulary than the mobile English vocabulary learning system without context-aware service. Additionally, 88.9% of learners are happy to learn other English curriculums using the proposed PCULS in the future.

Table 5. The preference comparison of both the learning modes.

Question	The proposed system with context-aware service (%)	The proposed system without context-aware service (%)
Do you prefer to learn English vocabulary by the proposed system with or without context-aware service?	72.2	27.8
Do you think that which learning mode can promote your learning motivation much more?	94.4	5.6
Do you think that which learning mode can make your score progress much more?	61.1	38.9
Do you think that which learning mode can deepen your memorised impression on vocabulary much more?	100	0
If there are similar English learning activities in the future, which learning mode do you prefer to use again?	88.9	11.1

4. Discussions

The section aims to propose several valuable discussion issues to extend the practicability of the proposed PCULS in real teaching scenes.

1. How to integrate the proposed PCULS with formal classroom English learning

Because the proposed PCULS was designed to support informal English vocabulary learning during the two 2-week learning activity considered in this study, all participating learners learned English vocabulary during their leisure time and without the assistance of teachers. Naismith and Corlett (2006) indicated that successful mobile learning should be integrated with formal classroom learning and the learning experiences of learners themselves. Indeed, the proposed ubiquitous English vocabulary learning activities could be further integrated with formal classroom learning activities and teacher can assist learner learning during learning processes. Performing this task requires teachers to implement curriculum planning and teaching strategies. However, to conduct this learning scenario requires the support of teaching materials, the learning location planning of schoolyard, the modification of teacher instruction strategy, and learner participation. The above considerations should be considered in properly integrating the ubiquitous learning process with formal classroom learning.

2. How to apply the proposed scheme to the vocabulary learning of any second languages

The PCULS proposed in this study can recommend appropriate English vocabulary to individual learners according to four contextual aspects. The experimental results demonstrated that the proposed system facilitates English vocabulary learning. Naturally, the proposed system can be applied to the learning of any language, with a corresponding difficulty parameter determined by Item Response Theory (IRT). Thus, the proposed learning mechanism offers an effective strategy for vocabulary learning in languages other than English.

3. The convenience of learning English vocabulary by mobile devices

Many studies have indicated that using PDA for learning activity is convenient (Davide Tosi & Roberto Bisiani, 2007; Doug Vogel, Kennedy, Kevin Kuan, Ron Kwok, & Jean Lai et al., 2007; Ogata, H. et al., 2006). In our experiment, the questionnaire responses indicated that few learners had experience of using mobile devices and accessing information through wireless network. See the data listed in Table 4 (the investigation results of the personal information). Numerous learners mentioned that access difficulties had prevented them from updating their learning portfolios or otherwise using the Internet, and these issues were not consistent with their expectation to be able to access the Internet everywhere. This reason may explain why the questionnaire results listed in Table 4 (the investigation results of the system operation) show that 17% of learners disagreed with the notion that PDAs facilitated learning. However, all learners could successfully access the Internet from selected locations in the schoolyard, and thus learners were encouraged to update their learning portfolios at these places. Therefore, the successful ubiquitous learning activity should be based on sufficient coverage of wireless connectivity to enable learners to properly appreciate the advantages of mobile devices and wireless technology.

5. Conclusions

This study created a prototype PCULS, which can recommend appropriate English vocabulary associated with providing context-awareness information to individual learners, to support effective English vocabulary learning. The proposed system developed a learner location estimation scheme based on back-propagation neural networks to support personalised context-aware ubiquitous English vocabulary learning. The accuracy rate in detecting learner location exceeds 92%, which is sufficient to aid situational English vocabulary learning. The proposed PCULS was successfully implemented on PDA to facilitate a seamless ubiquitous English learning environment without constraints of time or place. Moreover, a non-equivalent pre-test and post-test group based on the quasi-experimental design was performed in a high school to assess learners' learning performance after using the proposed context-aware ubiquitous English vocabulary learning system. The statistical results ($F = 5.785$, sig of $F = 0.022$) revealed that the learning performance of learners who used the personalised English vocabulary learning system with context-aware service is significantly based on the assessment of the pre-test and post-test, and exceeds the performance of learners who used the learning system without context-aware service according to ANCOVA analysis. Additionally, the questionnaire analysis indicated that over 50% of learners achieve satisfactory learning experiences after using the proposed PCULS. Furthermore, up to 72.2% of learners prefer English learning systems with context aware-service after experiencing two learning modes.

Acknowledgements

The authors thank the National Science Council of the Republic of China, Taiwan, (contract no. NSC96-S-2520-004-001) for financially supporting this research.

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