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Personalized mobile English vocabulary learning system based on item response theory and learning memory cycle

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Abstract

Since learning English is very popular in non-English speaking countries, developing modern assisted-learning tools that support effective English learning is a critical issue in the English-language education field. Learning English involves memorization and practice of a large number of vocabulary words and numerous grammatical structures. Vocabulary learning is a principal issue for English learning because vocabulary comprises the basic building blocks of English sentences. Therefore, many studies have attempted to improve the efficiency and performance when learning English vocabulary. With the accelerated growth in wireless and mobile technologies, mobile learning using mobile devices such as PDAs, tablet PCs, and cell phones has gradually become considered effective because it inherits all the advantages of e-learning and overcomes limitations of learning time and space that limit web-based learning systems. Therefore, this study presents a personalized mobile English vocabulary learning system based on Item Response Theory and learning memory cycle, which recommends appropriate English vocabulary for learning according to individual learner vocabulary ability and memory cycle. The proposed system has been successfully implemented on personal digital assistant (PDA) for personalized English vocabulary learning. The experimental results indicated that the proposed system could obviously promote the learning performances and interests of learners due to effective and flexible learning mode for English vocabulary learning.
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Keywords: Mobile learning; Personalized learning; English vocabulary learning; Item response theory; Learning memory cycle

1. Introduction

Fluent international communication is needed; therefore good language skills are very important. Any zlanguage learning can be divided into four issues including listening, reading, speaking, and writing skills; however, Huckin, Haynes, and Coady (1993) indicated that reading ability and vocabulary knowledge are two of the most important components of performance in a second language and depend on the other, especially in academic settings. Wilkins argued (1972) that "Without grammar very little can be conveyed, without

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vocabulary nothing can be conveyed.'' Oxford (1990a) pointed out that language learners typically have significant difficulty remembering large vocabularies. The English vocabulary has an extremely important role in English learning. In recent years, numerous studies have investigated English learning, and most emphasized the importance of vocabulary learning to English learning (DeCarrico, 2001). An excellent vocabulary is beneficial to inferring meaning from English sentences (Harmon, 1998, 2002; Rupley, Logan, & Nichols, 1999); however, countless learners think that memorizing English vocabulary is a difficult, especially when learning long or infrequently used words. A poor vocabulary frequently leads to misunderstanding content or poor comprehension when reading English articles (Lin, 2002; Segler, Pain, & Sorace, 2002). Many researchers conferred that the main obstacle in English learning is facing entirely new words in an English-language article (Anderson & Freebody, 1981; Mezynski, 1983; Qian, 2002). To read English articles fluently, a learner must understand at least 2000 commonly used English words (Nation, 1990). It is clear that vocabulary learning is central to English-language acquisition.

Additionally, forgetting learned vocabulary is another serious problem during learning English vocabulary. Forgetting is the loss of information over time. People typically recall information better just after learning than after a long delay. As time passes, information will be forgotten when no repeat learning process is performed. The speed of forgetting depends on factors such as the difficulty of learned material, its method of representation, and physiological factors such as stress and sleep quality. Additionally, the basal forgetting rates of individuals differ. A number of theories have attempted to explain why people forget information. The decay theory proposes that memory traces, formed in the brain when information is learned, gradually disappear over time. On the other hand, many psychologists thought that forgetting occurs as a result of interference from other information or activities over time. The first significant study investigating forgetting was conducted by German philosopher Hermann Ebbinghaus (1885). Ebbinghaus, based on experimental results, proposed the forgetting curve. However, memory strategies can help language learners to overcome forgetting. Memory strategies enable learners to store and retrieve information when needed. Oxford (1990a) subdivided memory strategies into the following four types: creating mental linkages; applying images and sounds; reviewing; and, employing actions.

Since English learning has been the most important second language in non-English speaking countries, developing modern assistive learning forms or tools that support effective English learning has been a crucial issue in the English-language education field. Recently, the fastest growing web community has been mobile visitors who browse web pages or retrieve web information using PDAs or cell phones via wireless networks. Similarly, the development of educational technologies recently has tended to be mobilized, portable, and personalized. These trends have led to learning forms changing from traditional classroom learning to electronic learning (E-learning) (Lee & Tan, 2003; Lin & Hsieh, 2001), mobile learning (M-learning) (Chang, Sheu, & Chen, 2003; Chen, Kao, Yu, & Sheu, 2004) or ubiquitous learning (U-learning) (Rogers et al., 2005; Wilkerson, Griswold, & Simon, 2005). Among these novel learning forms, mobile learning is effective and flexible; that is, mobile learning can overcome restrictions of time and space, enabling learners to study whenever and wherever possible. Recently, some scenarios of mobile learning have been successfully proposed to aid language learning activities of outside classroom, such as TenseITS, a PDA-based mobile intelligent tutoring system with learner's location awareness for supporting context language learning, designed primarily for Chinese learners of English (Cui & Bull, 2005), and using cell phones for assisting language learning (Chinnery, 2006; Collins, 2005; Kiernan & Aizawa, 2004).

Additionally, language learning strategies (LLS) are also important to language learning because many studies indicated that training students to use LLS can help them become better language learners (Canale & Swain, 1980; Oxford, 1990a; Segler et al., 2002). Oxford (1990b) has developed a fairly detailed list of LLS in her taxonomy. She distinguished language learning strategies into direct LLS, which directly involve the subject matter, i.e. the second language (L2) or (foreign language) FL, and indirect LLS, which do not directly involve the subject matter itself, but are essential to language learning nonetheless. Each of these broad kinds of LLS is further divided into LLS groups. Among the past-proposed language learning strategies, the communicative approach (Bialystok, 1990; Canale & Swain, 1980), which comes from learner desire to communicate in meaningful ways about meaningful topics, is a widely used teaching strategy to make use of real-life situations that necessitate communication. However, developing innovative language learning strategies for novel learning forms like mobile learning needs to pay more attentions in the future.

Therefore, this study presents a novel personalized mobile English vocabulary learning system that tailors English vocabulary learning materials to individual learners based on individual vocabulary abilities and learning memory cycles. This system allows learners to use the least time to achieve the most efficient learning of vocabulary. The proposed personalized mobile English vocabulary learning system evaluates a learner's vocabulary ability based on Item Response Theory (IRT), and then recommends proper learning materials for individual learners. This study also proposes a novel strategy, the learning memory cycle, which adjusts the review period for learning English vocabulary for individual learners based on an individual learner's memory cycle for various words. According to the difficulty of each word and individual learner vocabulary abilities, the proposed system plans adaptively a period for reviewing vocabulary for individual learners. The proposed system helps learners memorize English vocabulary efficiently, such that learned vocabulary is transferred to long-term memory via an efficient review process for individual learners and no longer forgotten. Furthermore, learners can learn English vocabulary in their spare time at any location that has a wireless network, as the proposed personalized mobile English vocabulary learning system has been implemented on handheld mobile devices. Compared with the communicative approach mainly focused on real-life language communication, the proposed English vocabulary learning strategy simultaneously considers adopting the peraonalized vocabulary learning based on individual vocabulary ability and extending individual memory cycles of various vocabularies to promote the effect of English vocabulary learning. Experimental results reveals that utilizing spare time to memorize English vocabulary via mobile devices is a practicable way of enhancing English vocabulary ability because mobile learning facilitates learning activities at any place and any time.

2. System design

This section describes the system architecture and personalized vocabulary learning scheme based on IRT and learning memory cycles of individual learners. First, an overview of system architecture is presented in Section 2.1. Sections 2.2 and 2.3 then describe the system components and details of how to evaluate the English vocabulary abilities of individual learners and recommend English vocabulary to individual learners using IRT. Sections 2.4 and 2.5 describe how to measure difficulty parameters of English vocabularies for evaluating English vocabulary abilities of individual learners and how to tune the learning memory cycles of individual learners.

2.1. System architecture

A personalized mobile English vocabulary learning system based on IRT and individual learning memory cycles of vocabularies, which includes a remote management server, client mobile learning system, and data synchronized agent, is presented. Fig. 1 presents the detailed system architecture. The client mobile learning system, which consists of three intelligent agents and three databases, can recommend new words to individual learners based on IRT and arrange vocabulary review cycles for individual learners. The remote management server, which has two databases and one data management interface, collects English vocabulary and manages vocabulary by an administrator (i.e., instructor). To support off-line learning, the data synchronized agent is responsible for maintaining data consistency between client databases and server databases after the wireless network connecting.

2.1.1. The remote management server

The left part of Fig. 1 presents the system architecture of the remote management server. The management server is built on the website allowing for easy management of learning material by an administrator. An administrator can add, modify, delete or edit learning content, as well as assess the leaning states of learners through data management interface.

2.1.2. The client mobile learning system

The right part of Fig. 1 shows the system architecture of the client mobile learning system. The client mobile learning system is implemented on PDAs, allowing learners to learn English vocabulary at any time and place.
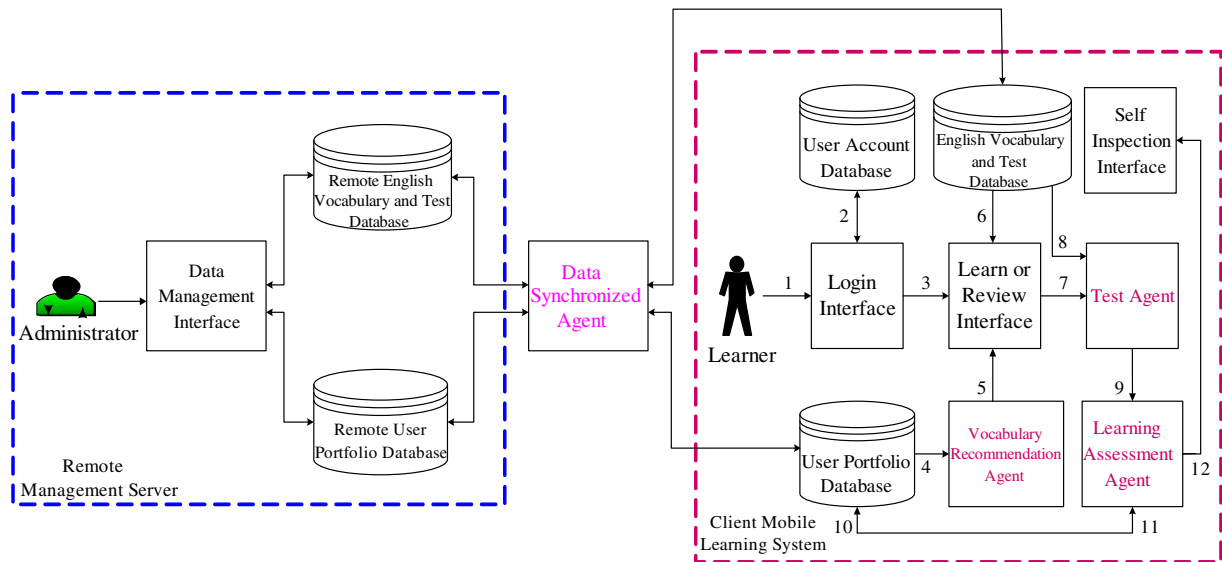
Fig. 1. The system architecture of personalized mobile English vocabulary learning system.

The system has the following three intelligent agents: a vocabulary recommendation agent; learning performance assessment agent; and, test agent. The vocabulary recommendation agent recommends a personalized English vocabulary to individual learners according to individual vocabulary abilities and memory cycles of learned vocabulary. The test agent automatically generates a corresponding test for vocabulary learned by individual learners for immediately assessment of learning performance. The learning performance assessment agent collects learner test results from the test agent, and then re-evaluated individual learner abilities and memory cycles of learned vocabulary. Finally, the learning performance assessment agent stores this information in the user portfolio database for personalized learning. Moreover, the proposed system has three learning interfaces—a login interface, learning and review interface and self-inspection interface. These learning interfaces provide a flexible and friendly learning interface allowing learners to interact with the three intelligent agents.

Based on system architecture, system operation procedures have three major processes—learning, testing and review processes. The system operation procedure is summarized as follows:

Step 1. Learner logs in the system via a login interface. When a learner logs in, the login interface checks his/her account in the user account database. If the learner is a beginner, the system guides the learner to execute the registration process, and then uses a pretest to evaluate his/her vocabulary ability.

Step 2. If a learner is registered, the system guides the learner to the main menu for personalized vocabulary learning or reviewing.

Step 3. The learner selects the learning or review process. The learning process is for learning new vocabulary and does not include the individual user portfolio. The review process reviews learned vocabulary to enhance the process of learned vocabulary and adjusting the memory cycle.

Step 4. The vocabulary recommendation agent obtains the vocabulary abilities of individual learners and memory cycles of all learned vocabulary from the user portfolio database.

Step 5 and Step 6. If a learner selects learn new vocabulary, the vocabulary recommendation agent then recommends new vocabulary with a corresponding difficulty parameter that closest to the learner's ability. When a learner selects review learned vocabulary, the vocabulary recommendation agent then recommends learned vocabulary with the shortest memory cycle to the learner.

Step 7 and Step 8. The test agent generates automatically a test to immediately assess or review performance according the learned vocabulary after the learner finishes learning or review process.

Step 9 and 10. The learning performance assessment agent re-evaluates learner vocabulary ability and memory cycles of learned vocabulary, and then stores these parameters in the user portfolio database.

Step 11 and Step 12. The learning performance assessment agent obtains the learning status of individual learners using the user portfolio database and presents this status to a learner through the self-inspection interface. The user then returns to **Step 3** for the next learning cycle or logs out, terminating the learning process.

2.2. Components of the client mobile learning system

2.2.1. The vocabulary recommendation agent

Estimating a learner's vocabulary ability based on IRT (Baker & Frank, 1992; Hambleton & Swaminathan, 1985; Hambleton, Swaminathan, & Rogers, 1991; Hulin, Drasgow, & Parsons, 1983) allows the vocabulary recommendation agent to recommend the appropriate vocabulary to learners. If a learner chooses to undertake the learning process, the vocabulary recommendation agent then recommends the most appropriate vocabulary to the learner according to the learner's vocabulary ability. The learned words are recorded in the user portfolio database for the review process. On the other hand, when a learner chooses the review process, the vocabulary recommendation agent then recommends the vocabulary with shortest memory cycle to the learner based on a learner's memory cycles for various words.

2.2.2. The test agent

To assess a learner's learning performance, the test agent randomly selects 10 test questions related to learned vocabulary to evaluate learning outcome. During the vocabulary learning, the test agent asks the learner to fill in the correct word in a blank to assess the learner's spelling and recall ability. In the vocabulary review process, the test agent asks a learner to identify the correct vocabulary from a list of several similar words to enhance the ability of a learner to recognize words and extend the vocabulary memory cycle. Moreover, the test agent manages the vocabulary difficulty based on vocabulary exposure (Parshall, Harmes, & Kromrey, 2000; Revuelta & Ponsoda, 1998) during the learning performance assessment process. The test agent decreases the difficulty of vocabulary for the vocabulary with high vocabulary exposure.

2.2.3. The learning performance assessment agent

To recommend suitable vocabulary for learners, the learning performance assessment agent re-evaluates learner vocabulary abilities and memory cycles of learned vocabulary based on test results after learners complete 10 randomly selected test questions. These re-evaluated learning parameters are then stored in the user portfolio database such that appropriate vocabulary can be recommended to individual learners during the next learning cycle. To comprehend the learning status of individual learners, the self-inspection interface summarizes learning information, including current vocabulary ability, top 10 words with short memory cycles, easily confused words, and ranking of grading score for individual learners. The aim of the self-inspection interface is to facilitate self-regulated learning.

2.3. Evaluating English vocabulary ability and recommending English vocabulary

Item Response Theory (Baker & Frank, 1992; Hambleton & Swaminathan, 1985; Hambleton et al., 1991; Hulin et al., 1983) is a widely used theory in education measurement, typically applied in the field of Computerized 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). Based on IRT, this study presents a novel personalized mobile vocabulary learning system for assessing learner vocabulary ability for personalized mobile learning services.

2.3.1. Evaluating English vocabulary ability

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. The formula for the item characteristic function with a single difficulty parameter is

$$P_j(\theta) = \frac{e^{D(\theta - b_j)}}{1 + e^{D(\theta - b_j)}} \quad j = 1, 2, \ldots, n \tag{1}$$

where $P_j(\theta)$ denotes the probability that learners can memorize and recognize the jth vocabulary at a level below their ability level θ, b_j is the difficulty of the jth vocabulary, n is the number of vocabularies and D is a constant 1.702.

In Eq. (1), the probability $P_j(\theta)$ is equal to 0.5 when a learner's vocabulary ability θ equals the difficulty parameter for the jth vocabulary word. Clearly, a learner must have a higher vocabulary ability to achieve a probability of 0.5 for memorizing the jth vocabulary word when the difficulty of the jth vocabulary word is increased.

In IRT, two methods are widely used when assessing a learner's ability—maximum likelihood estimation (MLE) and Bayesian estimation schemes (Baker & Frank, 1992; Hambleton & Swaminathan, 1985; Hulin et al., 1983). Although the MLE procedure is simple and easily implemented, it produces divergent estimations for a learner's vocabulary ability when a learner has completely correct or incorrect test responses for all learned vocabulary words (Baker & Frank, 1992). The MLE method frequently overestimates learner vocabulary ability when test responses are completely correct. Conversely, MLE typically underestimates learner vocabulary ability when test responses are completely incorrect. Compared with the MLE procedure, the Bayesian estimation method is more complex and less efficient, and can solve the divergent estimation problem in the MLE procedure. Basically, previous information for the distribution of learner vocabulary abilities is employed in this study to estimate learner vocabulary ability (Baker & Frank, 1992). Hence, the Bayesian estimation procedure always converges for all possible learner responses (Baker & Frank, 1992). Consequently, the Bayesian estimation procedure is applied to estimate learner vocabulary learning ability in this study. Bock and Mislevy (Baker & Frank, 1992) derived the quadrature form to estimate learner ability as

$$\hat{\theta} = \frac{\sum_k^q \theta_k L(u_1, u_2, \ldots, u_n | \theta_k) A(\theta_k)}{\sum_k^q L(u_1, u_2, \ldots, u_n | \theta_k) A(\theta_k) b} \tag{2}$$

where $\hat{\theta}$ denotes the learner's vocabulary ability of estimation, $L(u_1, u_2, \ldots, u_n | \theta_k)$ is the value of likelihood function at a level below their ability level θ_k and learner's responses are $u_1, u_2, \ldots, u_n$, θ_k is the kth split value of ability in the standard normal distribution, and $A(\theta_k)$ represents the quadrature weight at a level below their ability level θ_k.

In Eq. (2), the likelihood function $L(u_1, u_2, \ldots, u_n | \theta_k)$ can be further described as

$$L(u_1, u_2, \ldots, u_n | \theta_k) = \prod_{j=1}^{n} P_j(\theta_k)^{u_j} Q_j(\theta_k)^{1-u_j} \tag{3}$$

where $P_j(\theta_k) = \frac{e^{D(\theta_k - b_j)}}{1 + e^{D(\theta_k - b_j)}}$, $Q_j(\theta_k) = 1 - P_j(\theta_k)$, $P_j(\theta_k)$ denotes the probability that learners can memorize the jth vocabulary at a level below their ability level θ_k, $Q_j(\theta_k)$ represents the probability that learners cannot memorize the jth vocabulary at a level below their ability level θ_k, and u_j is the correct or incorrect testing response obtained from the vocabulary testing result to the jth vocabulary, i.e. if the answer is correct then $u_j = 1$; otherwise, $u_j = 0$.

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 memorizes the recommended vocabulary words and provides correct test responses, then a learner's vocabulary ability will be promoted based on the estimated formula for learner ability in Eq. (2); otherwise, learner vocabulary ability will be descended. The following subsection shows how appropriate vocabulary words are recommended to individual learners based on learner abilities using the information function.

2.3.2. Recommending English vocabulary and testing sheet

Two approaches in IRT are commonly used to recommend appropriate vocabulary words to learners—the maximum information strategy and Bayesian strategy (Baker & Frank, 1992; Hambleton & Swaminathan, 1985; Hulin et al., 1983). The maximum information strategy assumes that each vocabulary word with its corresponding difficulty parameter exhibits different information to a learner's learning. Vocabulary with a high information value is more suitable to be recommended to learners. Since the Bayesian strategy is more complex than the maximum information approach, the maximum information method is applied to recommend appropriate vocabulary. The maximum information function is defined as

$$I_j(\theta) = \frac{(1.7)^2}{[e^{1.7(\theta-b_j)}][1 + e^{-1.7(\theta-b_j)}]^2} \tag{4}$$

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

After calculating the information values for vocabulary words, the vocabulary recommendation agent recommends the vocabulary word that has a maximum information function to learners. A vocabulary word with the maximum information function value for a learner with θ ability indicates that the proposed system generates the highest recommendation priority.

2.4. Measuring the difficulty parameter of English vocabulary words

Generally, the difficulty of a vocabulary word is determined based on whether this vocabulary is easily memorized or recognized by learners. Many factors affect the difficulty of vocabulary for non-native English speakers. For example, one can logically infer that frequently used vocabularies in daily life are easier to learn than those infrequently used (Tozcu & Coady, 2004). Consequently, all English vocabularies are divided into the following five levels by the GEPT in Taiwan: elementary, intermediate, high-intermediate, advanced level, and superior level. Additionally, the number of letters in a word affects whether a learner can correctly spell and memorize this word. In addition, ability to pronounce a word also influences the difficulty of a vocabulary word.

To recommend appropriate vocabulary to individual learners, vocabulary words in different GEPT levels are considered to have various difficulties, and the proposed learning system then recommends vocabulary words with suitable difficulty to learners based on their abilities. To define the difficulty precisely, a questionnaire is utilized to determine the factors affecting difficulties of English words. Table 1 describes the questionnaire and presents questionnaire results. One hundred fifteen students who studied in Department of English Teaching at National Hualien University of Education were invited to fill out the questionnaire. Questionnaire results demonstrate that 98% learners believe that the frequency at which a vocabulary word is used is a factor influencing learning outcome when memorizing an English word. Moreover, over 82% learners thought that the length and pronunciation of a vocabulary word are also factors affecting learning outcome when memorizing words. Furthermore, a few respondents noted that professional vocabulary, learning circumstances, personal learning interests and word roots, prefixes and suffixes also affect difficulty in learning an English word.

In this study, three important factors—use frequency, length and pronunciation of a word—summarized from questionnaire results determine the difficulty of a vocabulary word. Measuring the difficulty of a vocabulary word by pronunciation is difficult. However, the phonetic symbols used in an English word comprise a practicable scheme for determining the difficulty of an English word. For example, the letter length of "straight" and "activity" is eight; however, the number phonetic symbols used in "straight" is fewer than that

Table 1
The investigation results of the factors that affect the difficulty of English vocabulary

Question	Satisfaction degree (%)				
	Strongly agreed	Agreed	No opinion	Disagreed	Strongly disagreed
I think that the frequently used vocabularies in daily lives are easier to be memorized than those of infrequently used vocabularies	60	38	1	1	0
I think that the character length of an English vocabulary will affect me to correctly spell and memorize this vocabulary well	26	56	13	5	0
The pronunciation is an important factor to affect me to memorize a vocabulary	37	47	13	3	0
Please list any factors which may influence you to memorize an English vocabulary well	Professional vocabularies				12
	Personal learning interests				14
	Learning circumstances				17
	Word root, prefixes and suffixes of a vocabulary				14

for "activity." In the word "straight", letters "ai" are mapped to single phonetic symbol, and letters "gh" are not be mapped to a phonetic symbol. The word "straight" is generally more difficult to memorize than the word "activity" for learners who memorize words using their phonetic symbols. Thus, the difficulty of each English vocabulary word can be measured using the following formula:

$$b_j = (L_j \times 0.7 + P_j \times 0.3) \times G_j \tag{5}$$

where b_j is the difficulty parameter of the jth vocabulary, L_j is the length parameter of the jth vocabulary, P_j is the phonetic parameter of the jth vocabulary, and G_j is the weight parameter of the corresponding GEPT grading level of the jth vocabulary.

2.4.1. Computing the length parameter of English vocabulary words

Currently, the proposed personalized mobile English vocabulary learning system contains 8032 words and a test database. The lengths of all words stored in the vocabulary and test databases have been computed and ranked. Here, assume the length of the longest vocabulary word is 100, the length of the shortest vocabulary is 0, and the length of a middle-order word is 50, then the length parameter for each English vocabulary word can be computed as

$$\begin{cases} L_j = 100 & \text{when } L_j = L_{\max} \\ L_j = 50 & \text{when } L_j = L_{\text{mid}} \\ L_j = 0 & \text{when } L_j = L_{\min} \\ L_j = 50 + (L_j - L_{\text{mid}}) \times \frac{100-50}{L_{\max}-L_{\text{mid}}} & \text{when } L_j > L_{\text{mid}} \\ L_j = 0 + (L_j - L_{\min}) \times \frac{50-0}{L_{\text{mid}}-L_{\min}} & \text{when } L_j < L_{\text{mid}} \end{cases} \tag{6}$$

where L_j is the length parameter of the jth vocabulary, $L_{\max}$ is the length of longest vocabulary among all vocabularies, $L_{\min}$ is the length of shortest vocabulary among all vocabularies, and L_{mid} is the length of middle-order vocabulary among all vocabularies.

2.4.2. Computing the phonetic parameter of English vocabulary

To compute the phonetic parameter of each word, the ratio of word length to phonetic symbol length is first defined as

$$PR = \frac{V_L}{P_N} \tag{7}$$

where PR is the ratio of the length of vocabulary to the length of phonetic symbols, V_L is the length of vocabulary, and P_N is the number of phonetic symbols.

Here, assume the phonetic parameter of a vocabulary word with largest PR is 100, and the phonetic parameter of a vocabulary word with smallest PR value is 0; thus, the phonetic parameter of the jth vocabulary word can be computed as

$$\begin{cases} P_j = 0 & \text{when } P_j = PR_{\min} \\ P_j = 100 & \text{when } P_j = PR_{\max} \\ P_j = \frac{100-0}{PR_{\max}-PR_{\min}} \times (PR - PR_{\min}) & \text{otherwise} \end{cases} \quad (8)$$

where P_j is the phonetic parameter of the jth vocabulary, $PR_{\max}$ is the largest ratio of the length of vocabulary to the number of phonetic symbols among all vocabularies, and $PR_{\min}$ is the smallest ratio of the length of vocabulary to the number of phonetic symbols among all vocabularies.

2.4.3. Determining the weight of the grading level of English vocabulary words

Since all English words stored in the English vocabulary and test databases are from the Taiwan GEPT, this study applied GEPT grading levels for vocabulary words to determine the weight of each word for computing the difficulty parameters of the English vocabulary words. The aim of the GEPT test is to fairly and reliably assess each level of English-language ability. The GEPT is currently divided into five levels, each level containing content appropriate to each level; each level has listening, reading, writing and speaking components. The elementary, intermediate, and high-intermediate GEPT tests are administered twice a year, the advanced GEPT test is held once yearly, and the superior level GEPT test is held when requested. Since the proposed system only contains vocabulary words for the previous three levels, the weight parameters in Eq. (5) for elementary, intermediate, and high-intermediate levels are 0.5, 1, and 1.5, respectively.

2.4.4. An example for computing the length and phonetic parameters of English vocabulary

Table 2 presents an example showing how to compute the length and phonetic parameters of each English vocabulary word. Suppose that $L_{\max}$, $L_{\min}$, and $L_{\mid}$ equal 14, 1, and 8, respectively, then the L_{3013}, L_{8031}, and L_1 are 50, 100, and 0. Therefore, the L_2 can be computed as

$$L_2 = 0 + (L_j - L_{\min}) \times \frac{50-0}{L_{\mid} - L_{\min}} = 0 + (2-1) \times \frac{50-0}{8-1} = 7.1429 \quad (9)$$

Moreover, suppose that $PR_{\max}$ and $PR_{\min}$ equal 1.6 and 1, respectively, then P_{3013}, P_1, and P_2 are 100, 0, and 0. Therefore, P_{3012} can be computed as

$$P_{3012} = \frac{100-0}{PR_{\max} - PR_{\min}} \times (PR - PR_{\min}) = \frac{100-0}{1.6-1} \times \left(\frac{5}{4} - 1\right) = 41.6667 \quad (10)$$

2.4.5. The distribution of the difficulties of English vocabulary words

Based on the definition of difficulty for English vocabulary words, Fig. 2 shows the distribution of difficulties of vocabulary words used in the learning system. The difficulties of vocabulary words in the proposed English vocabulary learning system have an approximately normal distribution with difficulty levels ranging from

Table 2
An example for computing the length and phonetic parameters of English vocabulary

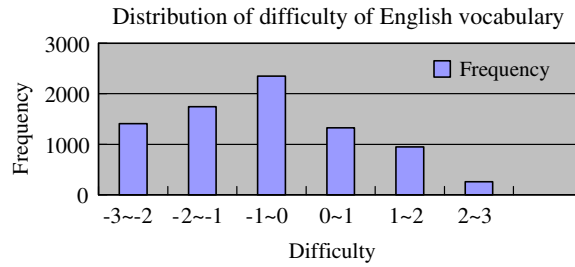| Vocabulary no.	Vocabulary	The length of vocabulary	L_j	PR	P_j
1	a	1	0	1/1	0
2	go	2	7.1429	2/2	0
...	...	...	...	...	...
3012	float	5	28.5714	5/4	41.6667
3013	straight	8	50	8/5	100
...	...	...	...	...	...
8031	constitutional	14	100	14/13	12.8167
8032	upbringing	10	66.6667	10/8	41.6667

Fig. 2. The distribution of the difficulties of 8032 English vocabularies in the learning system.

−3 to +3. The proposed English vocabulary learning system recommends vocabulary words with appropriate difficulties to individual learners according to their vocabulary abilities. Additionally, the difficulty of a vocabulary word also influences the learner memory cycle mentioned in Section 2.5. In addition, exposure to vocabulary is also considered in this study. If a learner reviews a vocabulary word numerous times during a learning process, the difficulty of the vocabulary word will reduce due to increased exposure to the word.

2.5. Tuning memory cycle of the learned English vocabulary for individual learners

Memory retention is an ability that preserves learned information (Wikipedia contributors, 2005). If a learner has not reviewed vocabulary words for a long time, memory retention will gradually decrease over time, i.e., a learned vocabulary word will forget. Unfortunately, no one can memorize everything learned. In other words, forgetting cannot be avoided; however, the speed at which one forgets differs among learners. The review process is a good strategy that enhances and extends learned material, thereby minimizing forgetting (Waugh & Norman, 1965). Each person has different retention abilities, even when learners are learning the same material. Hence, review cycles should be tailored to each person.

Ho (2005) proposed an English vocabulary learning scheme, based on individual memory cycles for reviewing learned vocabulary words, that extends the memory cycle for individual learners by increasing progressively sequence while the learner can give correct responses for tested vocabulary words. On the contrary, if a learner gives incorrect answers for tested vocabulary words, then the memory cycle will be repeatedly shortened based on decreasing progressively sequence until the learner can answer correctly. To consider further the differences in individual learner abilities and vocabulary difficulty levels, this study presents a novel review process—a modification of Ho's scheme—for English vocabulary learning based on individual memory retention ability. This review process can be adjusted based on learner vocabulary ability, the difficulty of learned English vocabulary words, and test results. Fig. 3 presents a comparison of the proposed memory cycle updating scheme with the scheme developed by Ho (2005). Tables 3 and 4 present the proposed strategies for tuning the memory cycle of an individual learner for learned vocabulary based on considering learner vocabulary ability and vocabulary difficulty simultaneously.

In summary, the proposed updating scheme for the memory cycle for learned vocabulary words for individual learners can be formulated as

$$
\begin{cases}
MC_{t+1}^{ij} = MC_t^{ij} + \frac{\widehat{\theta_i}}{b_j} \times F_{ot_{ij}} & \text{Correct response} \\
MC_{t+1}^{ij} = MC_t^{ij} - \frac{b_j}{\theta_i} \times F_{xt_{ij}} & \text{Incorrect response}
\end{cases}
\tag{11}
$$

where MC_{t+1}^{ij} is the updated memory cycle of the ith learner for the jth English vocabulary, MC_t^{ij} is the original memory cycle of the ith learner for the jth English vocabulary, θ_i represents the vocabulary ability of the ith learner, b_j is the difficulty parameter of the jth English vocabulary, ot_{ij} stands for the correct testing response times of the ith learner for the jth English vocabulary, xt_{ij} stands for the incorrect testing response times of the ith learner for the jth English vocabulary, and F represents Fibonacci sequence.

To avoid learners having negative vocabulary abilities, learner vocabulary ability in Eq. (11) is shifted from −3–+3 to +1–+7 when evaluating memory cycle. Moreover, the Fibonacci sequence F can be defined as

(a) Ho's memory cycle updating scheme

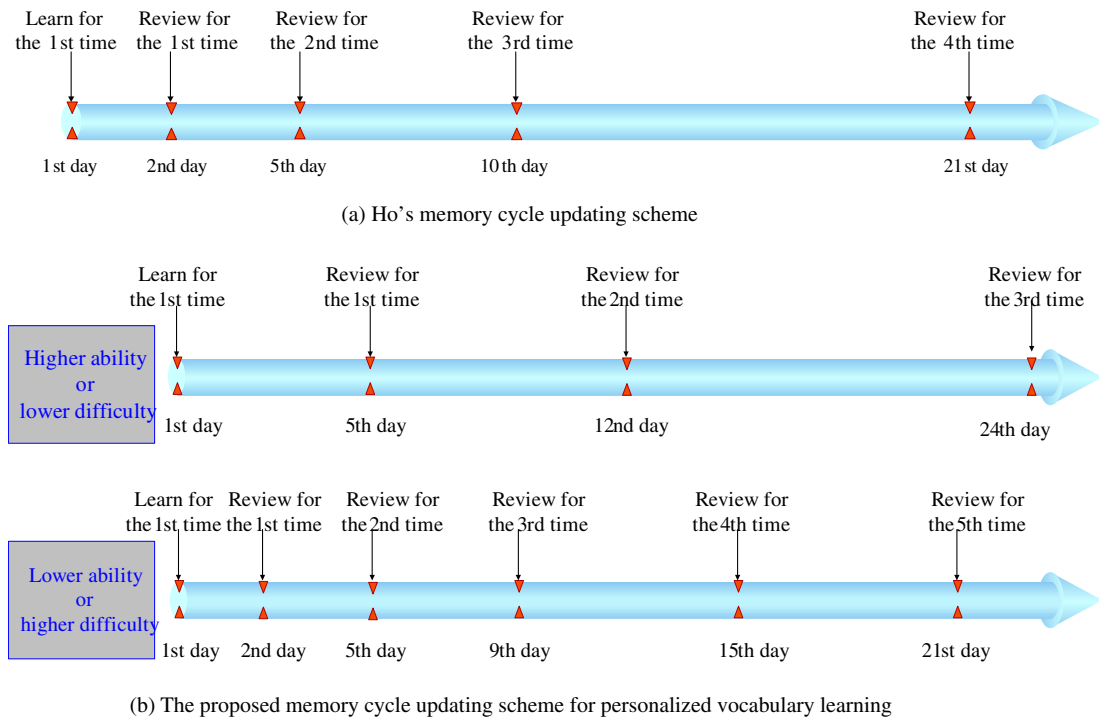(b) The proposed memory cycle updating scheme for personalized vocabulary learning

Fig. 3. Comparison of the memory cycle updating schemes between the proposed method with Ho's scheme while learner gives correct testing responses.

Table 3
The proposed strategies for adjusting memory cycle of the learned vocabulary based on learner vocabulary ability

The learner vocabulary ability vs. learning status	Acquired vocabulary	Non-acquired vocabulary
The learner with high vocabulary ability	Extending the memory cycle of the vocabulary by a long scale	Shortening memory cycle of the vocabulary by a short scale
The learner with low vocabulary ability	Extending the memory cycle of the vocabulary by a short scale	Shortening memory cycle of the vocabulary by a long scale

Table 4
The proposed strategies for adjusting memory cycle of the learned vocabulary based on the difficulty of vocabulary

The difficulty of vocabulary vs. learning status	Acquired vocabulary	Non-acquired vocabulary
The vocabulary with high difficulty	Extending the memory cycle of the vocabulary by a short scale	Shortening memory cycle of the vocabulary by a long scale
The vocabulary with low difficulty	Extending the memory cycle of the vocabulary by a long scale	Shortening memory cycle of the vocabulary by a short scale

$$\begin{cases} F_n = 1 & n = 1, 2 \\ F_n = F_{n-2} + F_{n-1} & \text{otherwise} \end{cases} \qquad (12)$$

The Fibonacci sequence is a recursive sequence; the next term is the sum of the preceding two terms. According to the forgetting curve proposed by Ebbinghaus (1885), when people remember something for a long time, the rate of forgetting is low. Conversely, when people learn new information, forgetting can occur quickly. Therefore, the property of increasing progressively in the Fibonacci sequence can be applied for adjusting

learner memory cycles. When a learner remembers a vocabulary word for a long time, his/her memory cycle should be extended much more; otherwise, the learner's memory cycle should be shortened.

Based on the proposed updating scheme for the memory cycle, when a learner responds correctly for English vocabulary test word, the learner's memory cycle will be extended based on vocabulary ability, the numbers of correct responses, and the difficulty parameter of the word. In other words, memory cycle will be extended when the difficulty parameter for the acquired word is small, the number of correct answers is high, and learner vocabulary ability is excellent. On the contrary, memory cycle will decrease when a vocabulary word not learned has a large difficulty parameter, the number of incorrect answers is high, and learner vocabulary ability is poor.

3. Experiments

This section first introduces the English vocabulary learning system implemented on the PDA. Moreover, to demonstrate the learning effectiveness of the proposed personalized mobile English vocabulary learning system, a group of university students were invited to participate in the experiment during five weeks. The experimental environment and results are detailed and analyzed below.

3.1. The system implementation

3.1.1. The developmental environment of software and hardware
In this study, Microsoft Visual Basic .NET 2003 was employed as the development tool to implement the proposed personalized mobile English vocabulary learning system. The software tool can support over two hundred kinds of web mobile devices including mobile phone and PDA to promote the development speed of applications. It is suitable to be employed to develop intelligent mobile devices like Pocket PC. The hardware of the designed system contains a courseware server and PDA client. The specifications of hardware are listed in Table 5.

3.1.2. The designed system interface
Fig. 4 shows the user interface of the designed system. Initially, learners must login the system, and then select the preferred learning activity. Basically, they can choose to learn English vocabularies, inspect their learning statuses or upload the client data to the remote user portfolio database in the remote management server. Fig. 4a displays the menu of learning activity. When a learner selects the item of vocabularies, he/she can perform the learning process or review process shown as Fig. 4b. First, if the learner selects the learning process, the vocabulary recommendation agent will recommend suitable English vocabularies to the leaner according his/her vocabulary ability. After learning these recommended English vocabularies, the test agent will perform the corresponding vocabulary test to examine the learner vocabulary ability and reveal the test results to the learner. Fig. 4c, d and e show the learning contents of the recommended English vocabulary, corresponding vocabulary test and vocabulary test result, respectively. Second, if the learner would like to review the required vocabularies, then the vocabulary recommendation agent will recommend the learned vocabulary with the shortest memory cycle among all review vocabularies to him/her. Fig. 4f shows the review vocabulary to enhance the learner's memory cycle for the learned vocabulary.

Except both the learning and review processes, the learner can inspect his/her learning statuses via the self-inspection interface. This mechanism provides benefits to encourage learners to make learning harder. First of all, individual learner can know which words that are frequently forgotten by him/her. Additionally, individ-

Table 5
The specifications of the hardware of the proposed system

	Courseware server (Windows 2000 Server)	PDA client (HP iPAQ h5550 Pocket PC PDA)
Processor	Intel Celeron 2.0 GHz	Intel(R) PXA255
Memory	SDRAM 512MB	SDRAM 512MB
Operating System	Microsoft Windows 2000 Server	Microsoft Windows CE 3.0
Database	Microsoft SQL Server 2000	Microsoft SQL CE 2.0

(a) The menu of learning activity

(b) The learning interface of vocabulary

(c) The learning contents of the recommended vocabulary

(d) The corresponding test of the learned vocabulary

(e) The test result

(f) The review vocabulary with the shortest memory cycle

(g) The self-inspection interface

(h) Reviewing the words that the learner forgot frequently by the self-inspection interface

(i) Observing the current vocabulary ability by the self-inspection interface

Fig. 4. The designed user interface of the personalized mobile English vocabulary learning system.

ual learner can also check his/her current vocabulary ability. Fig. 4g, h and i exhibit the self-inspection interface, the self-inspection results, and current vocabulary ability.

3.2. Experimental design

To assess the learning performance of the proposed personalized mobile English vocabulary learning system, this study recruited 15 three-year university students who were majoring in the Department of English Teaching at National Hualien University of Education to take part in this experiment as volunteers. The investigation was limited to only 15 participants owing to only limited sets of PDA equipment being available. All participants were undergoing training to become elementary school English teachers. The participants thus had received an education in basic teaching skills in the areas of English listening, speaking, reading and writing, with that education having lasted a minimum of three years. Since all participants were both volunteers and English teaching majors, they were highly interested in using the novel learning tool for English vocabulary learning, thus owning high learning motivations. Additionally, participants had no or very minimal experience of using PDA devices before participating the experiment. The 15 participants included two male students and 13 female students, ranging in age from 21 to 23 years old. The procedure of this experiment is displayed as Fig. 5. The testing sheets, which contain respectively 15 multiple-choice questions and 15 cloze questions averagely selected from three vocabulary levels of GEPT in Taiwan, were designed by an experienced English teacher for both the pre-test and post-test.

Before performing the experiment, 15 participants received the two hour training course on operating the PDA and using the proposed English vocabulary learning system, after which they were invited to perform a pre-test to assess their initial vocabulary abilities. The circumstances of the PDA operation training and the pre-test in a computer classroom are shown in Fig. 6a and b, respectively. After finishing the training course and the pre-test, each learner was distributed a PDA for use in English vocabulary learning by the proposed personalized mobile English vocabulary learning system during five weeks. Restated, the learners can freely use this handheld system without constraints of time and place to conduct ubiquitous English vocabulary learning. Meanwhile, the proposed system can immediately monitor learner learning states via the recorded learning portfolios during learning processes. Teachers can also observe recorded learning portfolios through the user interface of the remote management server. When learner fail to login to the system for two days, the proposed system will send an e-mail to remind them of their learning state. After five weeks, the 15 students were invited to perform a post-test to assess their English vocabulary abilities and completed a pre-designed questionnaire to assess their degree of satisfaction after learning.

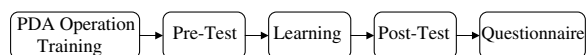PDA Operation Training → Pre-Test → Learning → Post-Test → Questionnaire

Fig. 5. Procedure of the experiment.

(a) PDA operation training   (b) The pre-test of English vocabulary

Fig. 6. The experimental scene in a computer classroom.

3.3. System evaluation

This section performed three evaluation procedures, including a pre-test, post-test, and questionnaire, to assess the learning outcomes for the proposed system. That is, system evaluation includes two parts which are the learning performance of learners and questionnaire results from learners' feedback responses.

3.3.1. Learning performance evaluation

Fig. 7 displays the comparison results of the learning performance for both the pre-test and post-test. The pre-test and post-test sheets were designed by an experienced English teacher who has taught English over 10 years, and the difficulties of both the testing sheets are controlled as identical according to the vocabulary difficulty mentioned in Section 2.4.

The perfect score is 30 points for the testing sheet containing 15 multiple-choice questions and 15 cloze questions. Although the learning performance of learners in terms of multiple-choice questions is not obviously promoted, Fig. 7b reveals that learners' vocabulary abilities in terms of cloze questions are obviously enhanced. To encourage us is that the entire performance of the post-test is superior to the pre-test. In order to compare the difference of the vocabulary abilities of the learners before and after using the proposed English vocabulary learning system, SPSS statistic software was used to analyze the results of pre-test and post-test. The results of paired samples t-test are listed in Table 6.

As the results of descriptive statistics listed in Table 6a, the mean scores of 15 learners for both the pre-test and post-test are 21.8 and 23.3333, respectively. Table 6b shows the difference of the mean scores between the pre-test and post-test is significant positive relation. It reveals that if a leaner got a high score in the pre-test, then he/she should also get a high score in the post-test. In addition, Table 6c gives the comparison results of the paired samples t-test of the pre-test and post-test scores. This study found that the difference of the mean scores between the pre-test and post-test score is -1.5333, the results reach the significant level under a degree of freedom of 14 ($t = -2.553$, $p = .023$). In other words, after using the proposed learning system, the promotion of learner learning performances is significant and the mean testing score increases 1.5333 points.

(a) The score distributions of multiple-choice questions

(b) The score distributions of cloze questions

(c) The score distributions of the entire performance for both the pre-test and post-test
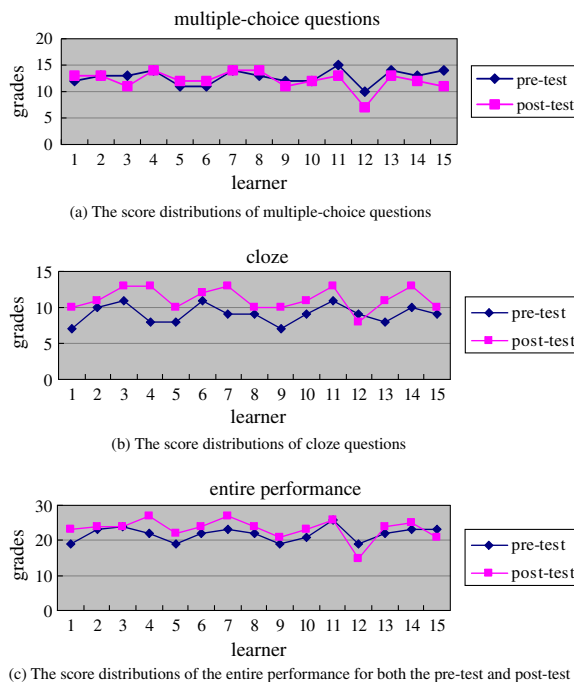
Fig. 7. The comparisons of learning performance for both the pre-test and post-test results.

Table 6
The paired samples t-test of the pre-test and post-test ($N = 15$)

		Mean	The number of samples	Std. deviation	Std. error mean
(a) Paired samples statistics					
Pair 1	Pre-test	21.8000	15	2.0771	.5363
	Post-test	23.3333	15	2.9439	.7601

	The number of samples	Correlation	Significance
(b) Paired sample correlation			
Pair 1 Pre-test and post-test	15	.619	.014

	Paired differences					t	df	Significance (2-tailed)
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
				Lower	Upper			
(c) Paired sample test								
Pair 1 Pre-test–Post-test	−1.5333	2.3258	.6005	−2.8213	−.2453	−2.553	14	.023

To further investigate the reasons that affect learner leaning performances, Table 7 lists the learning portfolios of five selected learners with excellent and poor learning performances. This study found that the number 4 learner who learned 740 vocabularies and reviewed them 1532 times has the best learning performance. On the other hand, the number 12 learner who learned only 250 vocabularies and reviewed them 240 times has the worst learning performance.

In order to understand the learning situations of both the number 4 and 12 learners, an informal interview was held by telephone. The number 4 learner indicated that she used the English vocabulary learning system every day, and performed the review process using leisure time. She thought that the proposed English vocabulary learning system is very helpful to English learning, especially in the provided cloze test, the immediate presentation of the test results and the vocabulary review strategy. She also suggested that the proposed system should add the function which can rank the learned vocabularies according to the learning date to help review those acquired vocabularies. Moreover, the number 12 learner indicated that she used infrequently the English vocabulary learning system for English vocabulary learning due to heavy lesson loading. However, she expressed that the provided review process is a good assisted tool to assist learning English vocabulary and the user interface provided by the proposed English vocabulary learning system is very friendly, she expressed that she is pleased to use this system again. Based on the illustrated learning portfolios listed in Table 7 and informal interview by telephone, this study thus concludes that the proposed English vocabulary learning system indeed provides some satisfied learning mechanisms to help the English vocabulary learning of individual learners if they own strong learning motivations to take more time for English vocabulary learning by the system.

Table 7
The illustrated learning portfolios of the learners with good and poor learning performances

Learner no.	The number of learned vocabularies	The number of times of performing the review processes	The progressive score between the pre-test and post-test
1	370	280	+4
4	740	1532	+5
7	912	4243	+4
12	250	240	−4
15	350	182	−2

3.3.2. Memory retention analysis of vocabulary review process

This section further investigates whether the proposed memory cycle updating scheme is beneficial to extending the learner memory retention of the reviewed vocabularies. Table 8 illustrates the statistical data of memory retention of 15 participants for the reviewed vocabularies. In particular, the number 7 learner has the best review performance because she reviewed all vocabularies among the 912 learned vocabularies and reached the highest vocabulary ability +3 during five weeks. Meanwhile, the average memory cycle of each vocabulary reviewed by her was extended from zero to 29.114 days under performing the review process of 4243 times. Actually, Table 7 also reveals that the number 7 learner has excellent learning performance because she reached the progressive score of 4 points after performing five weeks' learning and review processes. In addition, the average extended memory cycle per reviewed vocabulary of 15 learners is 3.79 days. This result proves that the proposed vocabulary review strategy can indeed help learner enhance the memory retention of the learned English vocabularies.

3.3.3. Questionnaire analysis

To evaluate learner satisfaction with the proposed PIMS system, referring to Chen's et al. research (Chen, Hsieh, & Hsu, 2007), a questionnaire which involves 18 questions divided into five types was designed to measure whether services provided in the proposed English vocabulary learning system satisfy actual learner requirements. The five question types contain the personal information about learner's learning by PDA, the convenience of the system operation, the investigation of the learners' learning attitude towards using the proposed learning system, the suggestions from learners' feedback responses, and the self-assessment of learners' English vocabulary ability before and after using the proposed English vocabulary learning system. Table 9 gives a summarization of the descriptions of question types. There are totally 15 learners who participated in our experiment and were invited to fill out this questionnaire after attending the five weeks' learning activity. The evaluation results of satisfaction degree are listed in Table 10. To conveniently observe the evaluating results, the investigation results of "strongly agreed" and "agreed" are merged as "approved", and the investigation results of "strongly disagreed" and "disagreed" are merged as "disapproved".

Table 10a lists the investigation results of the personal information. The evaluation results listed in Table 10b indicate that degree of satisfaction indicated by "approved" reaches 81.33% in relation to system

Table 8
The statistical data of memory retention of 15 participants for the reviewed vocabularies

Learner no.	The number of the reviewed vocabularies	The final learner vocabulary ability (−3 to +3)	The number of times of performing the review processes	The summation of the initial memory cycles of the reviewed vocabularies (day)	The summation of the tuned memory cycles of the reviewed vocabularies (day)	The average extended memory cycle per reviewed vocabulary (day)
1	210	2.992	280	0	354.080	1.686
2	307	2.999	382	0	392.520	1.279
3	70	2.983	79	0	85.696	1.224
4	720	3.000	1532	0	2891.104	4.015
5	32	1.649	38	0	49.577	1.549
6	202	2.997	265	0	346.302	1.714
7	912	3.000	4243	0	26551.700	29.114
8	400	2.998	53	0	74.732	1.868
9	90	2.973	115	0	138.533	1.539
10	380	2.997	814	0	1643.059	4.324
11	32	2.775	51	0	74.321	2.323
12	130	2.999	240	0	320.550	2.466
13	76	2.977	85	0	92.473	1.217
14	460	1.772	68	0	56.116	1.220
15	155	2.999	182	0	200.945	1.296
Average performance	278.40	2.81	581.60	0	2218.11	3.79

Table 9
The descriptions of question types

Question type	The number of questions	Description
Personal information about using PDA	3	To get the personal information about learners who attend the learning activity using PDA
System operation	5	Questions related to the user interface and the content of learning materials
Learning attitude	7	To investigate whether the system can enhance learners' learning motivation or interests and promote their learning achievements or not
Advantages and disadvantages of the proposed system	2	To ask learners for investigating the advantages and disadvantages of the proposed learning system
Self-assessment	1	To ask learners for self-assessing their English vocabulary abilities before and after using the proposed learning system

Table 10
The satisfaction evaluation results of questionnaire

Question type	Question	The number of learners	
		Yes	No
(a) The investigation results of the personal information			
Personal information about using PDA	Do you or your family have PDA or mobile phone with PDA?	2	13
	Do you use PDA first time?	13	2
	Have you ever used PDA for learning?	1	14

Question type	Question	Satisfaction degree (%)				
		Strongly agreed	Agreed	No opinion	Disagreed	Strongly disagreed
(b) The investigation results of the system operation						
System operation	I think that the mobile English vocabulary learning system provides a friendly user interface	27	60	0	13	0
	I am very clear about the learning procedure of the mobile English vocabulary learning system	33	60	0	7	0
	I can completely understand the meaning of learning materials that appears on the mobile English vocabulary learning system	13.33	73.33	0	13.33	0
	I think the mobile English vocabulary learning system is a good learning tool to assist English learning	0	67	0	33	0
	I agree that learning English by PDA is very convenient; because I can perform English learning at any time and place	13	60	0	27	0
	Average	81.33		0	18.67	
(c) The investigation results of the learning attitude						
Learning attitude	The design learning materials on the mobile English vocabulary learning system can promote my learning interests	0	60	6.67	26.67	6.67
	I often increase my learning time because learning by the proposed mobile English vocabulary learning system promotes my learning interests	13.33	53.33	6.67	26.67	0
	I think that using the mobile English vocabulary learning system can effectively promote my English vocabulary ability	20	73.33	0	6.67	0
	The self-inspection interface of the mobile English vocabulary learning system can prompt my learning motivation	20	53.33	0	26.67	0
	I agree that using PDA to learn English vocabulary is a very interesting learning mode	13.33	60	0	26.67	0
	After learning some vocabulary, a cloze test immediately given from the proposed system for the learned vocabulary is very helpful to test whether I have memorized the English vocabulary	20	33.33	0	40	6.67
	The review strategy of English vocabulary is very effective to me	20	46.67	0	33.33	0
	Average	69.53		1.9	28.57	

Table 10 (*continued*)

Question type	Question	Feedbacks from the learners	
(d) The investigation results of the learners' feedbacks			
Advantages and disadvantages of the proposed system	In your opinion, what are the advantages of this mobile English vocabulary learning system?	I can learn and review English vocabulary at any time and any place	53.33%
		I think that the review process is helpful to me to memorize vocabulary	46.66%
		The presentation of learning portfolio encourages me to learn more hard	13.33%
		The learning system provides a friendly user interface	13.33%
		The learning materials are very abundant	13.33%
	In your opinion, what are the disadvantages of this mobile English vocabulary learning system?	It will be better if the proposed English vocabulary learning system can provide a dictionary to help me look up some vocabularies I don't know	20%
		The illustrative sentences are not clear and interesting	20%
		The mode of review process is inflexible	6.66%
		The learning materials are not practical	6.66%
		The quality of hardware is poor	6.66%

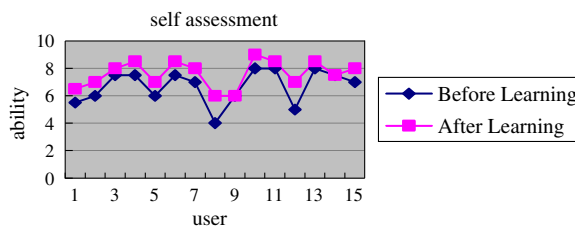| Question type	Question	Vocabulary ability		
		Learner number	Before learning	After learning
(e) The investigation results of the self-assessment				
Self- Assessment	This question aims at self-assessing your vocabulary ability. Please use the notations △ and ○ to indicate your vocabulary abilities based on the following ability scale before and after using this mobile English vocabulary learning system, respectively.	1	5.5	6.5
		2	6	7
		3	7.5	8
	0 1 2 3 4 5 6 7 8 9 10	4	7.5	8.5
		5	6	7
		6	7.5	8.5
		7	7	8
		8	4	6
		9	6	6
		10	8	9
		11	8	8.5
		12	5	7
		13	8	8.5
		14	7.5	7.5
		15	7	8
		Average	6.7	7.6

Fig. 8. The comparison of learners' self-assess vocabulary abilities before and after using the personalized mobile English vocabulary learning system.

operations. Table 10c indicates that 69.53% of learners satisfy the promotion of learning attitude. Moreover, Table 10d lists the results of investigation of the advantages and disadvantages of the proposed system. 53.33% of the learners addressed the convenience of the system, 46.66% of them thought that the proposed review process provides an excellent strategy to enhance their vocabulary abilities. On the other hand, 20%

Table 11
The paired samples *t*-test of the self-assessment vocabulary abilities of learners before and after learning ($N = 15$)

		Mean	Number of samples	Std. deviation	Std. error mean
(a) Paired samples statistics					
Pair 1	Pre-ability	6.7000	15	1.2218	.3155
	Post-ability	7.6000	15	.9673	.2498

	Number of samples	Correlation	Significance	
(b) Paired samples correlations				
Pair 1 Pre-ability and post-ability	15	.888	.000	

	Paired differences					*t*	df	Significance (2-tailed)
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
				Lower	Upper			
(c) Paired samples test								
Pair 1 Pre-ability–post-ability	−.9000	.5732	.1480	−1.2174	−.5826	−6.081	14	.000

of the learners suggested that the proposed English vocabulary learning system should add a dictionary function for looking up unfamiliar vocabularies, and 20% of them thought that the illustrative sentences are inappropriate and uninteresting to learners. Other suggestions were summarized in Table 10d.

Finally, this study also designed a self-assessed questionnaire so that learners can self-assess their English vocabulary abilities of before and after learning. The question asked learners to assess their English vocabulary abilities before and after learning based on a score scale with 10 different rankings. Thirteen learners among 15 learners thought that their vocabulary abilities are promoted after using the proposed system for English vocabulary learning, only two learners seem to keep the same vocabulary abilities, and no one thought their vocabulary abilities are descended. Table 10e shows the self-assessment results and Fig. 8 displays the comparison of learners' vocabulary abilities assessed by the learners themselves before and after using the personalized mobile English vocabulary learning system.

Additionally, to further analyze the vocabulary abilities self-assessed by the learners before and after using the proposed system, the paired samples *t*-test is used to compare the self-assessment results. The results of *t*-test are displayed in Table 11. As the statistical results listed in Table 11a, the results show learners' vocabulary abilities are obviously promoted from 6.7 to 7.6 after using the proposed English vocabulary learning system. Moreover, Table 11b indicates that the pre-ability and post-ability self-assessed by learners are significantly related. In addition, Table 11c displays the comparison results of the difference of the mean pre-ability with the mean post-ability self-assessed by the learners. The comparison results show that the difference is significant ($t = -6.081$, $p = .000$). That is, most learners thought that their English vocabulary abilities are clearly progressed after using the proposed English vocabulary learning system for English vocabulary learning.

The experimental results confirm that the English vocabulary abilities of most participants are promoted after using the proposed English vocabulary learning system. Although some learners' test scores in the post-test are descended, the results of the self-assessment listed in Table 10e indicate that they agreed that their English vocabulary abilities are promoted. In addition, to analyze the learning portfolios of the learners, we found that the effective factors affecting learning performance include mainly the leaning and review times. Moreover, the designed user interfaces and system performance are satisfied to most learners. Finally, some disadvantages of the proposed system with regard to system functions from the learners' feedback responses can be considered in our future work.

4. Conclusions

This study presents a novel personalized mobile English vocabulary learning system based on an evaluation of learner vocabulary ability using IRT and memory cycle adaptively tuned by the system for learned English

vocabulary words. The proposed English vocabulary learning system recommends vocabulary with an appropriate difficulty level to individual learners based on learners' vocabulary abilities. Moreover, the review strategy in the proposed learning system tunes the review cycle to individual learners based on the individual learner's vocabulary ability, difficulty parameters of learned vocabulary words and test outcomes for learned vocabulary. Experimental results demonstrated that most learners believe the review strategy is very helpful when learning English vocabulary. Additionally, experimental results reveal that the proposed personalized mobile English vocabulary learning system can significantly enhances learner English vocabulary abilities and promotes learning interests. More significantly, the proposed personalized mobile English vocabulary learning system facilitates a seamless ubiquitous learning environment for English learning without constraints of time or place by mobile devices.

Acknowledgements

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