Personalized curriculum sequencing utilizing modified item response theory for web-based instruction

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Abstract

Curriculum sequencing is an important research issue for Web-based instruction systems because no fixed learning pathway will be appropriate for all learners. Therefore, many researchers focused on developing e-learning systems with personalized learning mechanism to assist on-line Web-based learning and adaptively provide learning pathways. However, although most personalized systems consider learner preferences, interests and browsing behavior in providing personalized curriculum sequencing services, these systems usually neglect to consider whether learner ability and the difficulty level of the recommended courseware are matched to each other or not. Generally, inappropriate courseware leads to learner cognitive overload or disorientation during learning, thus reducing learning effect. Besides, the problem of concept continuity of learning pathways also needs to be considered while implementing personalized curriculum sequencing. Smoother learning pathways increase learning effect, avoiding unnecessarily difficult concepts. This paper presents a prototype of personalized Web-based instruction system (PWIS) based on the proposed modified Item Response Theory (IRT) to perform personalized curriculum sequencing through simultaneously considering courseware difficulty level, learner's ability and the concept continuity of learning pathways during learning. In the proposed modified IRT, the information function is revised to consider the concept continuity of learning pathway as well as considering the difficulty level of courseware and individual learner ability. Experiment results indicate that applying the proposed modified IRT for Web-based learning can construct suitable learning pathway to learners for personalized learning, and help them to learn more effectively.

Keywords: Item response theory (IRT); Computerized adaptive testing (CAT); Intelligent tutoring system; Personalization; Learning pathway

1. Introduction

Traditional teaching resources, such as textbooks, typically guide the learners to follow fixed sequence to other subject-related sections related to the current one during learning processes. Web-based instruction researchers have given considerable attention to flexible curriculum sequencing control to provide adaptable, personalized learning programs (Mia and Woolf, 1998; Lin and Hsieh, 2001; Lee, 2001; Tang and Mccalla, 2003; Papanikolaou and Grigoriadou, 2002; Jih, 1996; Tang et al., 2000; Brusilovsky et al., 1998). Curriculum sequencing aims to provide an optimal learning pathway to individual learner since every learner has different prior background knowledge, preferences, and often various learning goals (Hübscher, 2000; Weber and Specht, 1997; Brusilovsky and Vassileva, 2003). In an educational adaptive hypermedia system, an optimal learning pathway aims to maximize a combination of the learner's understanding of courseware and the efficiency of learning the courseware (Hübscher, 2000). Curriculum sequencing can generally be distinguished as either knowledge sequencing or task sequencing. Knowledge sequencing determines next teaching concept or topic (Brusilovsky, 1999). Task sequencing determines the next learning task (problem, example, test) within a current topic (Brusilovsky, 1999). However, finding an optimal learning pathway for individual learner is difficult and non-meaningful for tutoring systems because no measure exists by which to evaluate the success of an optimal learning pathway. Therefore, to provide adaptable learning pathway for individual learner is a more practicable in Web-based tutoring systems.

Moreover, as numerous Web-based tutoring systems have been developed, a great quantity of hypermedia in

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courseware has created information, cognitive overload and disorientation (Berghel, 1997; Borchers et al., 1998), such that learners are unable to learn very efficiently. To aid more efficient learning, many powerful personalized/adaptive guidance mechanisms, such as adaptive presentation, adaptive navigation support, curriculum sequencing, and intelligent analysis of student's solutions, have been proposed (Tang and Mccalla, 2003; Papanikolaou and Grigoriadou, 2002; Weber and Specht, 1997; Brusilovsky, 1999). Adaptation is particularly important in Web-based education for at least two general reasons (Brusilovsky, 1998). First, most Web-based applications are designed for a much wider variety of users than standalone application. That is, a Web application designed with a particular class of users in mind may not suit other users. Second, in many cases the user is alone working with a Web-based tutoring system. This is similar to a teacher typically providing adapted teaching content for an individual classroom student. Besides, personalized service has also received considerable attention (Mobasher et al., 2000) recently in Web application systems because of information needs differing among users. Examples of such systems include the Citeseer website for literature search (NEC Research Institute ResearchIndex) (Research), the Yahoo search engine for web page search (Yahoo! Search Engine) and product recommendation agents for e-commerce (Xiao et al., 2003). Currently, most adaptive/personalized tutoring systems (Lee, 2001; Tang and Mccalla, 2003; Papanikolaou and Grigoriadou, 2002) consider learner/user preferences, interests, and browsing behavior when investigating learner behavior for personalized services. However, these systems neglect the importance of learner ability when implementing personalized mechanisms. On the other hand, some researchers emphasized that personalization should consider levels of learner knowledge, especially in relation to learning (Papanikolaou and Grigoriadou, 2002; Brusilovsky, 1999). That is, the ability of individuals may be based on major fields and subjects. Therefore, considering learner ability can promote personalized learning performance.

The Item Response Theory (IRT) (Baker, 1992; Hambleton, 1985; Hulin et al., 1983) is a popular theory in education measurement. It is usually applied in computerized adaptive testing (CAT) (Horward, 1990; Hsu and Sadock, 1985) to select appropriate testing items for examinees based on individual ability. The computerized adaptive testing cannot only efficiently shorten the testing time and the number of testing items, but also precisely estimate examinee ability. Presently, the concept of CAT is applied to replace traditional measurement instruments (which are typically fixed-length, fixed-content and paper-pencil tests) in several real-world applications, such as TOEFL (TOEFL), GRE (GRE), and GMAT (GMAT).

To construct a personalized learning pathway based on simultaneously considering courseware difficulty level, learner ability and learning concept continuity during learning processes, a personalized Web-based instruction system based on the modified Item Response Theory is here presented to provide personalized curriculum sequencing services. The single parameter logistic model with difficulty parameter proposed by Georg Rasch (Baker, 1992; Hambleton, 1985; Hulin et al., 1983) is applied to model various difficulty levels of courseware. In addition, IRT with modified information function is presented to compute matched degree for appropriate course materials recommendations. This is because the original information function in Item Response Theory (Baker, 1992; Hambleton, 1985; Hulin et al., 1983) only considers the matched degree of difficulty level of courseware with the learner's ability to recommend courseware for learner. To recommend a learning pathway using the original information function for individual learner leads to the obstacle of the discontinued learning pathway, resulting in unnecessarily advanced concept learning. In modified Item Response Theory, the information function is revised in relation to concept continuity of the learning pathway. In this study, after the SCORM metadata of courseware in the courseware database is first processed by the Chinese natural language processing (NLP) technique, i.e. CKIP (CKIP), the cosine-measure (Frakes and Baeza-Yates, 1992; Chowdhury, 2004) is applied to calculate concept relation degrees among courseware. The concept relation degrees are applied to modify the original information function in IRT in order to obtain a smoother learning pathway for personalized curriculum sequencing. PWIS dynamically estimates learner ability based on the proposed modified IRT by collecting learner feedback after studying the recommended courseware. Based on the estimation of learner abilities, the system can recommend courseware with appropriate difficulty levels to learners using the modified information function. Restated, learner ability and the difficulties of course materials are simultaneously taken into account when implementing a personalization mechanism. Meanwhile, the problem of concept continuity of learning pathway is also considered while implementing personalized curriculum sequencing because the information function revision is based on concept relation degrees.

In summary, the proposed PWIS based on the modified IRT provides learning paths that can be adapted to various levels of difficulty of course materials and various abilities of learners. Meanwhile, the concept continuity of learning pathways is also integrated by analyzing concept relation degrees for all database courseware while applying personalized curriculum sequencing. To prevent the learner from becoming lost in course materials, the system provides personalized learning guidance, filters out unsuitable course materials to reduce cognitive loading, and provides a fine learning guidance based on individual user profile. Experimental results indicate that the proposed PWIS can recommend appropriate course materials to learners based on individual ability, and help them to learn more effectively in a web-based learning environment.

2. System architecture

This section describes the system architecture and personalized curriculum sequencing approach using the proposed modified Item Response Theory. First an overview of system architecture is presented in Section 2.1. Sections 2.2 and 2.3 then describe the system components and detail the Item Response Theory with the modified information function.

2.1. System architecture

Here, a personalized curriculum sequencing approach for the proposed PWIS system based on the modified Item Response Theory, which includes an off-line courseware modeling process, four intelligent agents and four databases, is presented herein. The four intelligent agents are the learning interface agent, feedback agent, courseware recommendation agent and courseware management agent, respectively. These four databases include the user account database, user profile database, courseware database and teacher account database. The learner interface agent aims at providing a flexible learning interface for learners to interact with the feedback agent and the courseware recommendation agent. The feedback agent aims at collecting learner explicit feedback information from the learning interface agent and storing it in the user profile database for personalized curriculum sequencing operations. The courseware recommendation agent is in charge of recommending a personalized learning pathway to learner according to learner feedback response and concept relation degrees of courseware. Finally, the courseware management agent with authorized account management mechanism provides a responsive courseware management interface, aiding teachers to create new course units, upload courseware to the courseware database and delete or modify courseware from the courseware database. The system architecture is shown as Fig. 1. Furthermore, we also propose a courseware modeling process derived from the computerized adaptive testing (CAT) theory (Horward, 1990; Hsu and Sadock, 1985) to assign courseware with appropriate difficulty parameters for personalized curriculum sequencing service. The proposed courseware modeling process successfully transfers the item-testing concepts into courseware to provide courseware resources with the corresponding difficulty parameter for personalized curriculum sequencing service. The following section details the system architecture operating procedure.

Based on the system architecture, the details of system operation procedure are described as follows:

Step 1. Courseware experts design testing items for learning content. According to the IRT, the difficulty parameters of these testing items can be determined through statistical method. After that, courseware with web page type can be designed according to the conveying concept of the corresponding testing item. The detailed courseware modeling process is described in Section 2.2. The designed courseware can be maintained through the courseware management agent and stored into the courseware database.

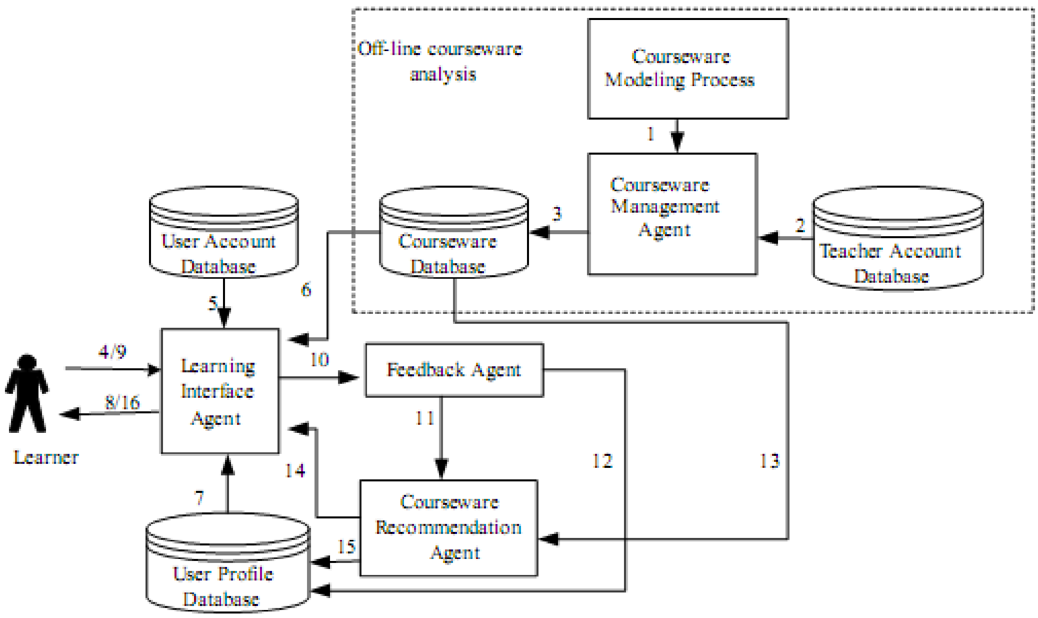

Fig. 1. The system architecture.

Step 2. Teachers access the system to upload, delete or revise courseware in the courseware database by the legal teacher's accounts.

Step 3. Teachers maintain the courseware database through the courseware management agent.

Step 4. Learner logs in the system through the learning interface agent.

Step 5. As a learner logs in the system, the learning interface agent checks his account in the user account database. If the learner has already registered, the system will get his learning profile from the user profile database.

Step 6. The learning interface agent gets the contents of courseware from the courseware database and exhibits them for the learner.

Step 7. If the learner has owned a legal account in our system, the learning interface agent will get his past learning records from the user profile database to provide personalized learning service. Otherwise, the system will add a new record into the user profile database for this learner.

Step 8. As the learning interface agent gets learner's information from the courseware database, user account database and user profile database, the system will recommend an appropriate courseware to learner.

Step 9. The learner needs to reply to two simple questionnaires, i.e. the difficulty level and the comprehension percentage for the learned courseware in order to provide personalized learning service.

Step 10. The learning interface agent passes the learner feedback information to the feedback agent.

Step 11. The courseware recommendation agent evaluates the learner ability according to the learner's feedback responses using the modified IRT.

Step 12. The feedback agent records the learner's feedback responses into the user profile database.

Step 13. The courseware recommendation agent obtains the difficulty parameters of learned courseware from the courseware database.

Step 14. The courseware recommendation agent calculates the corresponding information function value of each courseware in the learned courseware unit according to the evaluated learner ability, difficulty parameter of courseware and concept relation degrees of courseware, then ranking all courseware by the order of modified information function values. Finally, it transfers the results to the learning interface agent and offers a list of recommended courseware for the learner.

Step 15. The learner information, which includes ability, learner response, and learning paths, as calculated by the courseware recommendation agent will be recorded in the user profile database.

Step 16. The learning interface agent displays a list of recommended courseware for the learner and waits for his/her feedback response. After the learner selects the next courseware for further learning, the system's operating procedure will return to *Step 8*, and will continue to run the learning cycle from *Step 8* to *Step 16* until the learner logs out the system.

2.2. System components

2.2.1. Courseware modeling process

The courseware modeling process presents a detailed courseware design procedure to establish the difficulty parameters of courseware and courseware contents for personalized courseware recommendation. In our previous study (Chen et al., 2005), a voting approach was proposed to determine difficulty parameters of courseware by integrating experts' decision and learners' voting through a linear combination with different weights. However, the method assumes learners will provide completely confident voting results to fine tune the difficulty parameters of courseware predefined by course experts. This method might be subjective and easily influenced by learners' abilities and background knowledge. Therefore, this study prefers a statistics-based method through a conscientious test process to determine the difficulty parameters of courseware. Since this strategy derives from the computerized adaptive testing (CAT) theory, it is more reasonable and logical than the previous work. The detailed flowchart of the courseware modeling process is illustrated as Fig. 2.

To design a course of C language programming as an example, several experienced teachers were invited as courseware experts to analyze the primary concepts for the course of C language programming in the courseware modeling process. The courseware experts also designed the corresponding testing item for each learning concept. That is, the testing items are regarded as key characteristic of the corresponding learning content. Besides, about 500 examinees who have majored in the course of C language programming to join the exam, which contains 33 testing items to cover those learning concepts. According to the IRT, their testing data was analyzed by the BILOG program to obtain the appropriate difficulty parameters for these testing items. After that, the web page of courseware was designed following the conveying content of the corresponding testing item. Since the content of courseware is derived from the concept of the testing item, it is assigned the difficulty of courseware equals the difficulty of

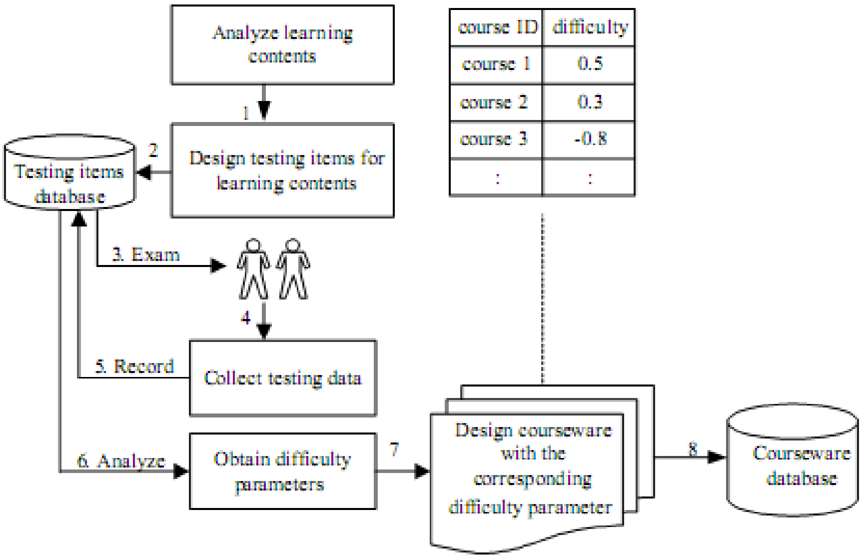

Fig. 2. Courseware modeling process.

the corresponding testing item in this study. This approach avoids some subjective factors from learners with different knowledge background, thus can obtain more confident difficulty parameters for personalized curriculum sequencing service.

2.2.2. *Courseware management agent*

The courseware management agent administers the details of maintaining the courseware database. This agent provides a friendly user interface for teachers to upload, delete or revise the content of courseware in the courseware database. By checking the accounts of teachers in the teacher account database, the system only permits a user with legal account to manage the courseware database through the user-interface. Using this interface, system administrator also manages teachers' accounts, course categories, course units and course content. In order to facilitate easier courseware exchange with other e-learning systems, all courseware in the courseware database has followed the standard of SCORM 1.2 (Sharable Content Object Reference Model) metadata information model (Advanced Distributed Learning; SCORM, 2001). Each courseware in the courseware database has a corresponding XML binding file to record important SCORM metadata, which conveys the main courseware concept. Meanwhile, the courseware management agent also provides an interface for teachers to maintain the SCORM metadata for the relevant courseware. In this study, both the fields of description and keyword in the SCORM metadata information model are used to calculate the concept relation degrees among courseware for modifying the original information function using Chinese natural language processing (CKIP) and information retrieval (Frakes and Baeza-Yates, 1992; Chowdhury, 2004) methods. Fig. 3 illustrates the maintained interface of SCORM metadata in this system.

2.2.3. *Learning interface agent*

The learning interface agent provides a friendly learner interface to interact with learners, conveys the learners' feedback information to the feedback agent, and receives the recommendation result from the courseware recommendation agent. Through the learning interface agent, learners can choose interesting course categories and units to study. Learners can also enter appropriate keywords for searching the needed courseware for content through the system's search mechanism during a learning process. If a learner visits the personalized Web-based instruction system for the first time, he/she must register as a legal user by inputting his/her e-mail address. After a beginner logs into, the learning interface agent will select courseware with moderate difficulty for him/her and ask him/her to reply to two simple questionnaires as described in a later section for personalized curriculum sequencing service during a learning process. The learning interface agent will convey the learner's response to the feedback agent and courseware recommendation agent for evaluation and consequent recommending of appropriate courseware. If the learner is an experienced learner, the system will get his/her previous ability in this course unit from the user profile database, and recommend appropriate courseware.

2.2.4. *Feedback agent*

In order to facilitate more precise personalized curriculum sequencing mechanisms, learner must provide feedback responses by replying to two simple questions, i.e. the difficulty level and the comprehension degree for the recommended courseware. The feedback agent gathers this information from the interface agent into the user

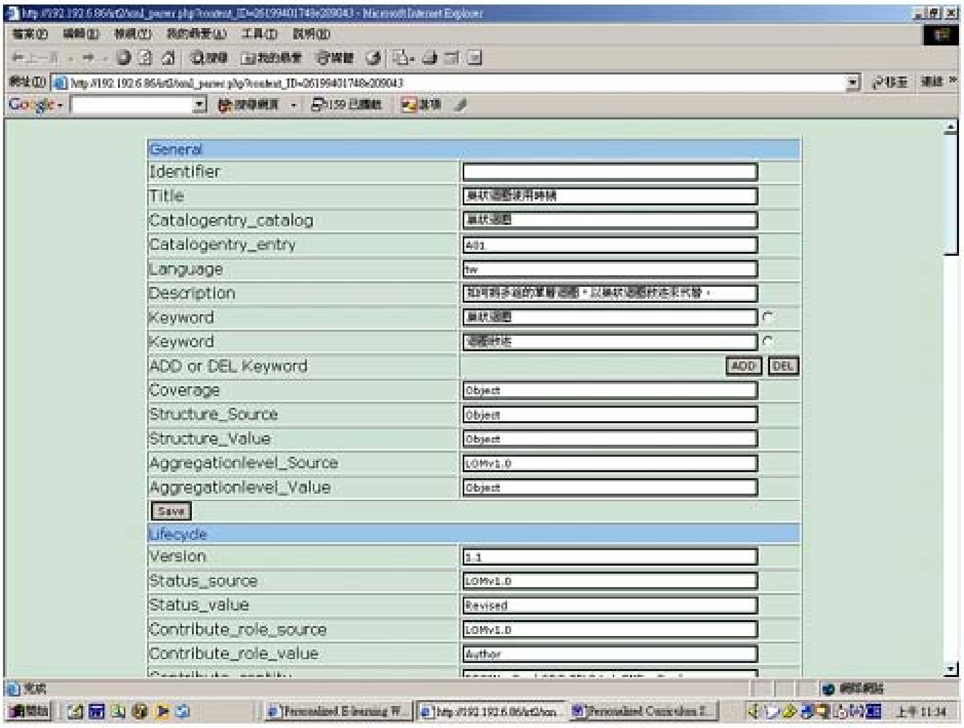

Fig. 3. The maintained interface of SCORM metadata in our system.

profile database. According to the IRT, if a learner understands the content of the learned courseware, then his/her ability in the course unit will be promoted. Conversely, a learner's ability will be descended if he/she cannot understand the learned courseware content. The original IRT can correctly estimate learner ability by learner's response (i.e. understanding or not understanding answer). Finally, the feedback agent conveys the feedback information, i.e. difficulty level and understanding or not, to the courseware recommendation agent in order to evaluate learner ability and recommend appropriate learning courseware to learners.

2.2.5. Courseware recommendation agent

Estimating the learner's ability enables the system to recommend the appropriate courseware to learners. The courseware recommendation agent first estimates learner ability using the Bayesian estimation procedure, then evaluates the modified information function value of courseware and ranks courseware based on the modified information function value of courseware for personalized courseware recommendation. Fig. 4 illustrates the operation procedure of the courseware recommendation agent. The following subsections first describe how to evaluate learner's ability and recommend appropriate courseware to learners based on the IRT in detail.

2.2.5.1. Courseware modeling and learner's ability estimation. To estimate learner's ability, the item characteristic function with a single difficulty parameter proposed by Rasch (Baker, 1992; Hambleton, 1985; Hulin et al., 1983) is used to model the courseware. The formula of item characteristic function with single difficulty parameter is defined as follows:

$$P_j(\theta) = \frac{e^{D(\theta - b_j)}}{1 + e^{D(\theta - b_j)}} \tag{1}$$

where $P_j(\theta)$ denotes the probability that learners can understand the jth courseware at a level below their ability level θ, b_j is the difficulty of the jth courseware, and D is a constant 1.702.

Two methods are widely used in assessing learner's ability. They are the maximum likelihood estimation (MLE) and Bayesian estimation approaches (Baker, 1992; Hambleton, 1985; Hulin et al., 1983). Although, the procedure of MLE is simple and easily implemented, it has the problem of producing divergent estimation for learner's ability when the learner gives complete understanding or not understanding responses for all learned courseware during a learning process (Baker, 1992). MLE will overestimate learner's ability in the completed understanding case. Conversely, MLE underestimates learner's ability in the completed not understanding case. Compared with the procedure of MLE, although Bayesian estimation method is more complex and less efficient, it can nevertheless solve the divergent estimation problem in the MLE procedure. Basically, prior-information on the distribution of the learner's abilities is employed here to estimate learner's ability (Baker, 1992). Hence, the Bayesian estimation procedure always converges for all possible learners'

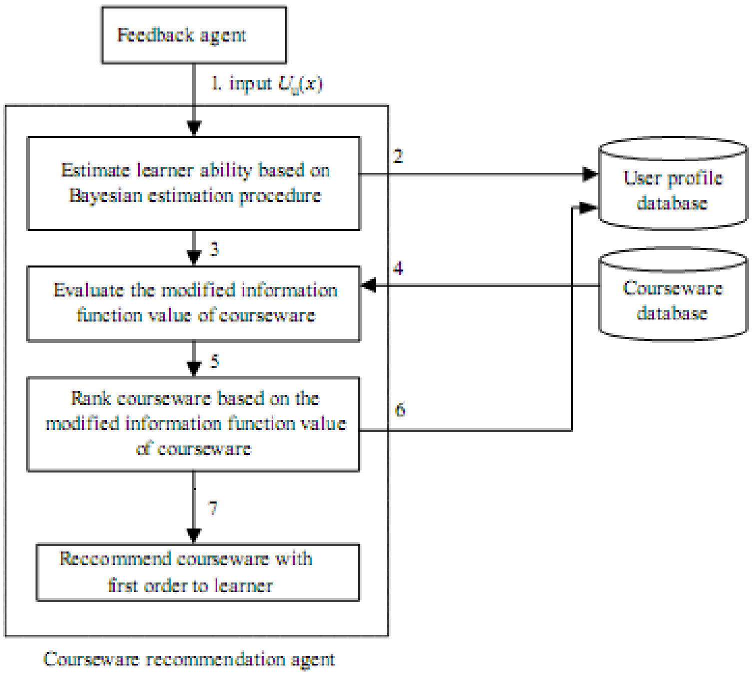

Fig. 4. The operation flowchart of courseware recommendation.

responses (Baker, 1992). For this reason, the Bayesian estimation procedure is applied to estimate learner's ability in this study. Bock and Mislevy (Baker, 1992) derived the quadrature form to approximately estimate learner's ability as follows:

$$\hat{\theta} = \frac{\sum_{k}^{q} \theta_k L(u_1, u_2, \ldots, u_n | \theta_k) A(\theta_k)}{\sum_{k}^{q} L(u_1, u_2, \ldots, u_n | \theta_k) A(\theta_k)} \quad (2)$$

where $\hat{\theta}$ denotes the learner's 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 follows:

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

where $P_j(\theta_k) = (e^{D(\theta_k - b_j)}/(1 + e^{D(\theta_k - b_j)}))$, $Q_j(\theta_k) = 1 - P_j(\theta_k)$, $P_j(\theta_k)$ denotes the probability that learners can understand the jth courseware at a level below their ability level θ_k, $Q_j(\theta_k)$ represents the probability that learners cannot understand the jth courseware at a level below their ability level θ_k, U_j and is the understanding or not understanding answer obtained from learner feedback to the jth courseware, i.e. if the answer is understanding then $U_j = 1$; otherwise, $U_j = 0$.

In the system presented here, learner abilities are limited to between -1 and $+1$. That is, learners with ability $\theta = -1$ are viewed as the poorest, those with ability $\theta = 0$ are viewed as having moderate abilities, and those with ability $\theta = 1$ are viewed as having the best abilities. This system estimates learner abilities based on learner feedbacks. If learners can understand the content of the recommended course material, then learner abilities will be promoted based on the estimated formula of learner abilities mentioned in Eq. (2); otherwise, learner abilities will be demoted. The current system sends the abilities of new learners to the course recommendation agent, after which the course recommendation agent ranks a series of appropriate course materials in the course database according to the new ability. The next two subsections show how to recommend appropriate course materials to learners based on learner abilities using the information function and modified information function, respectively.

2.2.5.2. Courseware recommendation using information function. In IRT, two approaches are used to recommend appropriate courseware to the learner. They are the maximum information strategy and Bayesian strategy (Baker, 1992; Hambleton, 1985; Hulin et al., 1983), respectively. Maximum information strategy emphasizes that each courseware with the corresponding difficulty parameter exhibits different information to learner's learning. Courseware with higher-information value is more suitable to be recommended for the learner. Since the Bayesian strategy is more complicated than the maximum information approach, the maximum information method is applied to recommend appropriate courseware. The maximum information function is defined as follows:

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

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

After calculating the corresponding information values of courseware in a course unit, the course recommendation agent can recommend a series of courseware to learner with ability θ according to the ranking order of information function value. A courseware with the maximum information function value under learner with ability θ indicates that the system presented here gives the highest recommendation priority. Whether the learner accepts the recommended courseware with highest recommendation priority or selects the other recommended courseware to do further learning, our system will record learner's learning paths and learner's feedback responses into the user profile database during a learning process. The learning information in the user profile database is also helpful for developing personalized learning pathway analysis and learning diagnosis mechanisms.

2.3. Item response theory with the modified information function

Since the original information function in IRT only considers the matched degree of difficulty level of courseware and learner's ability to recommend courseware, the problem arises of discontinued learning pathway. Therefore, this section explains how the concept relation degrees can be applied to modify the original information function in IRT to obtain a smoother learning pathway for personalized curriculum sequencing.

2.3.1. Metadata preprocessing

First, two metadata fields of the corresponding XML binding file of courseware are selected to represent the conveyed learning concept for a courseware. They are description and keyword fields in the SCORM 1.2 metadata information model shown as Fig. 3, respectively. In order to calculate the concept relation degrees for modifying the information function in the original IRT, metadata preprocessing is required because the description field in the SCORM 1.2 metadata information model is described using Chinese natural language in this study. Thus, the first phase of metadata preprocessing aims to perform word segmentation using Chinese knowledge information processing (CKIP) in order to describe the metadata field of the corresponding XML binding file of courseware so that separated linguistic terms can be obtained. The second phase of metadata preprocessing filters out non-textual words (e.g. numeric data, symbols, notation and ASCII drawings) and one-word terms because they do not carry any usable information for calculating concept relation degrees.

2.3.2. Estimation of concept relation degree

To estimate the concept relation degree of two courseware, the vector space model (Frakes and Baeza-Yates, 1992; Chowdhury, 2004) is applied to represent each courseware as vectors in a multi-dimensional Euclidean space. Each axis in this space corresponds to a linguistic term obtained from word segmentation process. The coordinate of the ith courseware in the direction corresponding to the kth linguist term can be determined as follows:

$$w_{ik} = tf_{ik} \times \log\frac{N}{df_k} = tf_{ik} \times \mathrm{IDF} \quad (5)$$

where w_{ik} represents the importance/weight of the kth term in the ith courseware, tf_{ik} is the term frequency of the kth term, which appears in the ith courseware; N denotes the total number of courseware in a course unit, df_k is the document frequency of the kth term, which appears in a course unit.

Assume that there are total m terms under union of all linguistic terms of the ith courseware and jth courseware. The concept relation degree for the ith and jth courseware can be found using the cosine-measure, and listed as follows:

$$r_{ij} = \frac{\sum_{h=1}^{m} w_{ih} w_{jh}}{\sqrt{\sum_{h=1}^{m} w_{ih}^2 \sum_{h=1}^{m} w_{jh}^2}} \quad (6)$$

where $c_i = \langle w_{i1}, w_{i2}, \ldots, w_{ik}, \ldots, w_{im} \rangle$ and $c_j = \langle w_{j1}, w_{j2}, \ldots, w_{jk}, \ldots, w_{jm} \rangle$, respectively, represent the vectors in a multi-dimensional Euclidean space for the ith and jth courseware, r_{ij} denotes the concept relation degree between the ith and jth courseware.

Assume that there are totally n courseware in a course unit, the concept relation matrix for all courseware can be expressed by the matrix **R**, and listed as follows:

$$\mathbf{R} = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_n \end{array} \\ \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix}_{n\times n} \end{array} \quad (7)$$

2.3.3. Modified information function

This section describes the details of the modified information function. Assume that the learner has learned the kth courseware in a course unit. Thus, the modified information function applied to recommend the next most appropriate courseware for the learner could be represented as follows:

$$I_j'(\theta) = (1-w) \times \frac{(1.7)^2}{[e^{1.7(\theta-b_j)}][1+e^{-1.7(\theta-b_j)}]^2} + w \times r_{kj}, \quad j = 1 \sim n, \quad \text{but} \quad j \neq k \tag{8}$$

where $I_j'(\theta)$ is the modified information function value of the jth courseware at a level below their ability level θ after the learner has learned the kth courseware, b_j is the difficulty parameter of the jth courseware, r_{kj} is the concept relation degree of the kth courseware with jth courseware, and w is an adjustable weight.

In Eq. (8), the modified information function derived from a linear combination of the original information function and the concept relation degree of the kth courseware with the jth courseware is applied to perform curriculum sequencing for individual learner. The roles of both parameters b_j and r_{kj} in the Eq. (8) are easily observable according to their mathematical meaning. From Eq. (8), we can infer that if the ability level θ of a learner is closer to the difficulty parameter b_j, then the value of the modified information function is larger. Similarly, if the concept relation degree r_{kj} is higher, then the value of modified information function is also larger. That is, a larger value of modified informartion function represents a more appropriate courseware for learners. In our system, the course recommendation agent can recommend a series of courseware to a learner with ability θ according to the ranking order of modified information function value after calculating the corresponding modified information function values of courseware in a course unit.

3. Experiments

To verify the learning efficiency and effectiveness for the proposed personalized curriculum sequencing approach, the prototype of the system has been successfully implemented and some university students who have majored in the course of C language programming were invited to test this system. Currently, the URL address of the web site is available at http://192.192.6.86/irt2/. The detailed functions of this system and experimental results are described as follows.

3.1. Course terminologies

Various course terminologies related to course design are first explained to describe experimental results. Courses created by teachers using the course management interface, can be categorized as titles of 'Neural Networks' and 'C Language Programming', etc. Moreover, a course can be further divided into several course units by analyzing teaching content. Furthermore, a course unit involves many relevant course materials that convey similar concepts, but such course materials are associated with different levels of difficulty. The course modeling process determines the difficulty parameter of each piece of course material. That is, course material organized on a single Web page is the smallest course element in the proposed system. For example, the course unit, 'Loop', in the course category, 'C Language Programming', includes many similar course materials with various levels of difficulty, to convey the concept of the 'Loop'.

3.2. Experimental environment

At present, the proposed prototype is implemented on the platform of Microsoft Windows 2000 with IIS 5.0 Web server. Moreover, the front-end script language of PHP 4.3 and MySQL server are used to implement this system. As a learner logs into this system, a course unit that is interesting to them can be chosen. Fig. 5 shows the entire layout of the learning interface. In the left frame, system shows the course categories, course units and the list of all courseware in the courseware database. While a learner clicks a courseware for learning, the content of selected courseware will be exhibited in the upper-right window. Besides, the feedback interface is arranged in the bottom-right window. The proposed system can get learner's feedback response from the interface of feedback agent through learner replies to two questionnaires shown as Fig. 6.

The answer of question one can be served as an investigation of learner's satisfactory degree for the recommended courseware. The 5-point Likert-scale proposed by Likert in 1932 (Likert, 1932) is applied to define various scaled answers. In a variation of standard Likert-scale, this study uses a scale where -2 indicates 'very easy', -1 is 'easy', 0 is 'moderate', 1 is 'hard' and 2 is 'very hard'. If a learner feels that the recommended courseware is quite suitable to him, then the averaged value of his answers should be very close to zero, i.e. 'Moderate'. The answer of question two helps system to get the learner's understanding degree for the recommended courseware. The system conveys these two feedback responses to the courseware recommendation agent to evaluate learner ability. After a learner presses the button of analysis, this system will reveal a list of the recommended courseware based on his current ability. Fig. 7 shows an example of courseware recommendation based on learner ability after learner gives corresponding feedback response, and the recommended courseware ranked by the order of their information values. The title (標題) indicates the subject of the courseware; the recommendation (推薦指數) denotes the information value of the recommended courseware; and the description (描述) gives a brief description for the corresponding courseware. The length of bar line in the column of recommendation indicates the information value of

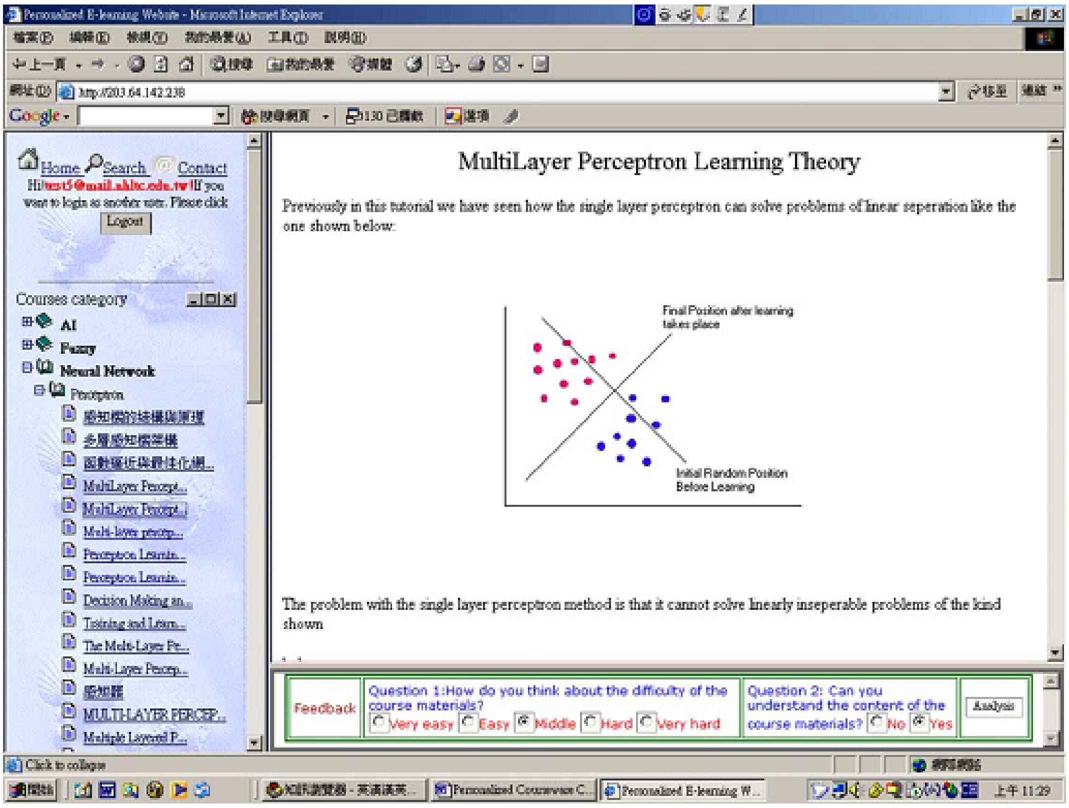

Fig. 5. The entire layout of learning interface for learner.

the corresponding courseware. The longer bar line implies a more suitable courseware for learner. On the contrary, the shorter bar line implies an unsuitable courseware for learner. The study frequency shows the learned frequency of courseware by a learner from past to nowadays. Moreover, the understanding degree shows the learner feedback response for the second questionnaire. This display of information can help learner to understand his/her current learning situation in a course unit. Besides, Fig. 8 shows the interface of the courseware management agent for teachers to tune the difficult parameters for courseware in a course unit.

3.3. Experimental results and analysis

The course unit, 'Loop' under the course category, 'C Language Programming', is used to obtain the experimental results because this course unit presently contains more course materials to support personalized curriculum sequencing. Currently, the 'Loop' unit includes a total of 33 course materials with various levels of difficulty to convey similar concepts of loop. One hundred seventeen learners logged in the system, and the user profile database includes 1731 records.

3.3.1. Estimation of learner's ability

Currently, this system only contains a small amount of courseware because to produce high quality courseware needs a large amount of manpower to join this work. In our experiments, C language programming is selected as a course unit to provide personalized curriculum sequencing services. All designed courseware of C language programming and their corresponding difficulty parameters determined by the proposed courseware modeling process are listed in Table 1. Actually, to expand the courseware database and supply more abundantly courseware for learners are urgently needed in our future work. In this system, the range of learner's ability and difficulty parameter of courseware are limited from -1 (i.e. lowest ability and simplest courseware) to $+1$ (i.e. highest ability and most difficult courseware). As a learner logs in this system, if the user account database does not have any

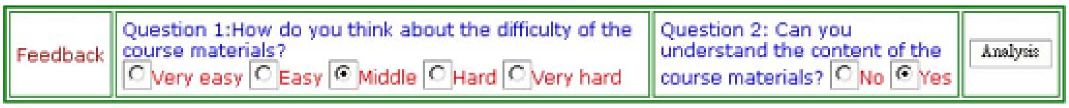

Fig. 6. Two questionnaires for getting learner's feedback information.

Fig. 7. An example of courseware recommendation ranked by the order of information values.

Fig. 8. The interface of the courseware management agent for tuning the difficulty parameters of courseware.

Table 1
The corresponding difficulty parameter for each courseware in the 'Loop' unit

Title of courseware	Difficulty parameter
巢狀迴圈(使用時機) Using opportunity of nested loop	0.4
FOR 迴圈(應用實例二) Example 2 of "for" instruction	0.57
FOR 迴圈(應用實例一) Example 21of "for" instruction	-0.1
FOR 迴圈(使用時機) Using opportunity of "for" instruction	-0.5
FOR 迴圈(迴圈定義) Definition of "for" instruction	0.1
FOR 迴圈(流程說明) Flowchart of "for" instruction	-0.27
巢狀迴圈(迴圈定義) Definition of nested loop	0.27
巢狀迴圈(應用實例一) Example 1 of nested loop	0.3
巢狀迴圈(應用實例二) Example 2 of nested loop	0.7
巢狀迴圈(應用實例三) Example 3 of nested loop	0.53
while 語法介紹 Introduction of syntax of "while" instruction	0.1
while 流程圖 Flowchart of "while" instruction	0.23
while 迴圈範例（一） Example 1 of "while" instruction	0.4
while 迴圈範例（二） Example 2 of "while" instruction	0.3
do while 語法介紹 Introduction of syntax of "do while" instruction	0.17
do while 流程圖 Flowchart of "do while" instruction	0.1
do while 迴圈範例（一） Example 1 of "do while" instruction	0.23
do while 迴圈範例（二） Example 2 of "do while" instruction	0.37
無窮迴圈介紹 Introduction of infinite loop instruction	0.17
無窮迴圈流程圖 Flowchart of infinite loop instruction	0.37
無窮迴圈範例（一） Example 1 of infinite loop instruction	0.1
break 語法介紹 Introduction of syntax of "break" instruction	0.17
break 流程圖 Flowchart of "break" instruction	-0.3
break 範例（一） Example 1 of "break" instruction	0.13
break 範例（二） Example 2 of "break" instruction	0.13
continue 語法介紹 Introduction of syntax of "continue" instruction	0.067
continue 流程圖 Flowchart of "continue" instruction	-0.3
continue 範例（一） Example 1 of "continue" instruction	0.067
continue 範例（二） Example 2 of "continue" instruction	0.23
goto 語法介紹 Introduction of syntax of "goto" instruction	0.1
goto 流程圖 Flowchart of "goto" instruction	-0.17
goto 範例（一） Example 1 of "goto" instruction	0.13
goto 範例（二） Example 1 of "goto" instruction	0.37

history records in the selected course unit for this learner, then his initial ability will be regarded as 0. That is, the system assumes learner's ability is moderate level. As a learner clicked the recommended courseware for learning, his/her ability in this course unit will be re-evaluated according to his/her feedback responses and the corresponding difficulty parameter of the learned courseware. Figs. 9 and 10 show the plots of relationship between the difficulty parameters of the clicked course materials with the adjustment of the learner's ability. In Fig. 9, the learner is

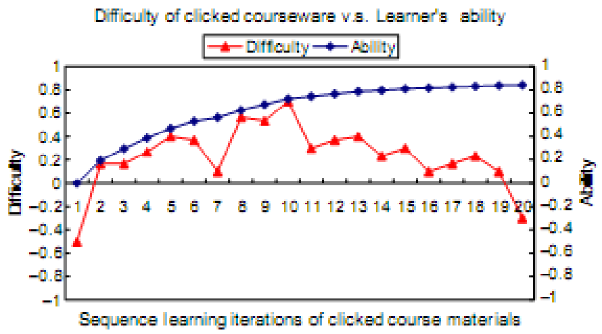

Fig. 9. The relationship between the difficulty parameter of the clicked course material and the adjustment of the learner's ability for learner with high ability.

assumed to respond 'yes' to the question, 'Do you understand the content of the recommended course materials?' asked of the 20 clicked course materials. If learners understand the more difficult recommended course materials, then the tuned value of learner ability will be large. In contrast, if learners understand less difficult course materials, the tuned value of learner ability will be small. Conversely, in Fig. 10, the learner is assumed to respond 'no' to the question, 'Do you understand the content of the recommended course materials?' asked of the 20 clicked course materials. These two experimental results imply that the proposed system can indeed correctly evaluate learner's ability according to the difficult level of learned courseware using Bayesian estimation procedure.

3.3.2. Curriculum sequencing using the original information function

To observe the effect of personalized curriculum sequencing, the original information function is first applied to perform the curriculum sequencing service. Figs. 11 and 12 present the relationship between the ability of the learner to the difficulty parameter of the recommended course material for learners with various abilities. The experimental result shows the difficulty parameter of the recommended course material is strongly correlated with learner ability. This result implies that the proposed system can indeed recommend appropriate

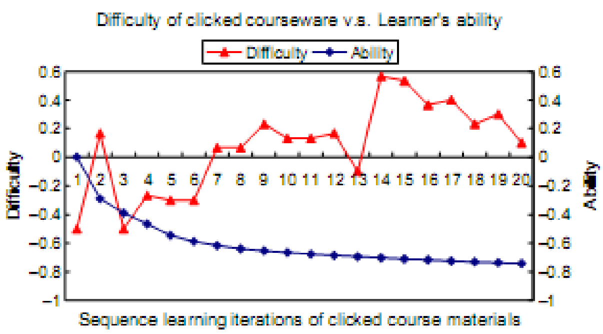

Fig. 10. The relationship between the difficulty parameter of the clicked course material and the adjustment of the learner's ability for learner with low ability.

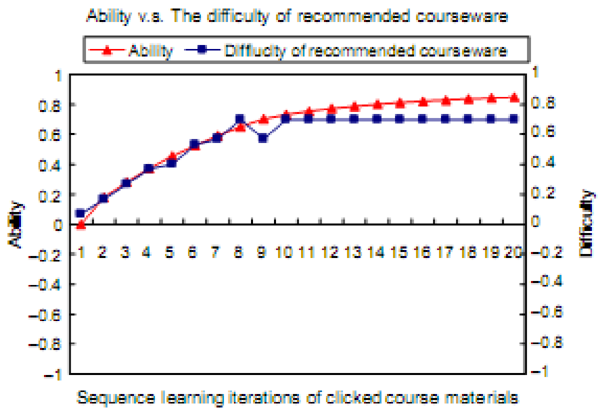

Fig. 11. The relationship between learner's ability and the difficulty parameter of the recommended course material for learner with high ability.

course materials to learners, according to their abilities. Moreover, the experimental result in Fig. 11 indicates that the proposed system recommends the same courseware with difficulty parameter 0.7 to learner from the 10th to the 20th learning iterations. Meanwhile, the experimental result in Fig. 12 also indicates that the proposed system recommends the same courseware with difficulty parameter −0.5 to learner from the 6th to the 20th learning iterations. This phenomenon is logical because the courseware with difficulty parameters 0.7 and −0.5 is the most difficult and simplest courseware in the 'Loop' unit, respectively.

Next, to analyze the learning pathway recommended by the original information function, the experiment of learning process is performed to obtain the learning pathway sequence for the learners with various abilities. Tables 2–4 illustrate the corresponding learning process recommended by the original information function for learners with high, low and moderate abilities, respectively. In our experiments, assume that learner accepts to learn the courseware according to the ranking order of courseware recommended by our system if the recommended courseware has not been learned by learner. In this manner, if the recommended

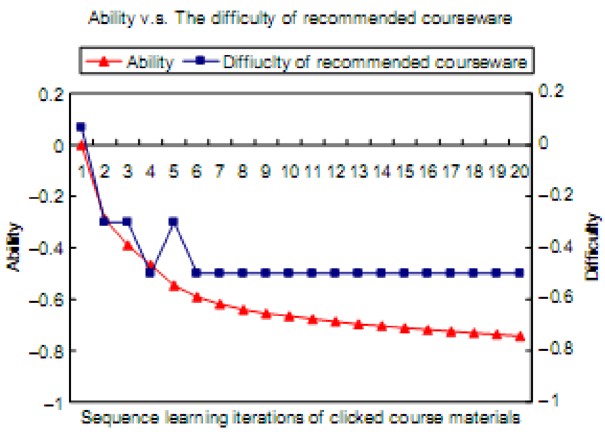

Fig. 12. The relationship between learner's ability and the difficulty parameter of the recommended course material for learner with low ability.

Table 2
The learning process recommended by the original information function for a learner with high ability

Learning iteration	Clicked courseware	Recommended courseware of top 1	Concept relation degree of the clicked courseware with the recommended courseware of top 1	Difficulty parameter of clicked courseware	Difficulty parameter of recommended courseware of top 1	Learner's ability	Do you understand of the clicked courseware ?
1	FOR 迴圈(使用時機) Using opportunity of "for" instruction	continue 語法介紹 Introduction of syntax of "continue" instruction	0.347404	-0.5	0.067	0.046716	yes
2	continue 語法介紹 Introduction of syntax of "continue" instruction	無窮迴圈介紹 Introduction of infinite loop instruction	0.46291	0.067	0.167	0.179688	yes
3	無窮迴圈介紹 Introduction of infinite loop instruction	巢狀迴圈(迴圈定義) Definition of nested loop	0.695379	0.167	0.267	0.282149	yes
4	巢狀迴圈(迴圈定義) Definition of nested loop	goto 範例(二) Example 1 of "goto" instruction	0	0.267	0.367	0.373026	yes
5	goto 範例(二) Example 1 of "goto" instruction	巢狀迴圈(使用時機) Using opportunity of nested loop	0	0.367	0.4	0.455490	yes
6	巢狀迴圈(使用時機) Using opportunity of nested loop	巢狀迴圈(應用實例三) Example 3 of nested loop	0.353553	0.4	0.533	0.524606	yes
7	巢狀迴圈(應用實例三) Example 3 of nested loop	FOR 迴圈(應用實例二) Example 2 of "for" instruction	0.612372	0.533	0.567	0.592243	yes
8	FOR 迴圈(應用實例二) Example 2 of "for" instruction	巢狀迴圈(應用實例二) Example 2 of nested loop	0.447214	0.567	0.7	0.649553	yes
9	巢狀迴圈(應用實例二) Example 2 of nested loop	FOR 迴圈(應用實例二) Example 2 of "for" instruction	0.447214	0.7	0.567	0.705143	yes
10	while 迴圈範例(一) Example 1 of "while" instruction	巢狀迴圈(應用實例二) Example 2 of nested loop	0.302372	0.4	0.7	0.732993	yes
11	do while 迴圈範例(二) Example 2 of "do while" instruction	巢狀迴圈(應用實例二) Example 2 of nested loop	0.410792	0.367	0.7	0.755257	yes
12	無窮迴圈流程圖 Flowchart of infinite loop instruction	巢狀迴圈(應用實例二) Example 2 of nested loop	0.0447214	0.367	0.7	0.774577	yes
13	while 迴圈範例(二) Example 2 of "while" instruction	巢狀迴圈(應用實例二) Example 2 of nested loop	0.380319	0.3	0.7	0.789283	yes
14	巢狀迴圈(應用實例一) Example 1 of nested loop	巢狀迴圈(應用實例二) Example 2 of nested loop	0.92338	0.3	0.7	0.80243	yes
15	do while 迴圈範例(一) Example 1 of "do while" instruction	巢狀迴圈(應用實例二) Example 2 of nested loop	0.298142	0.233	0.7	0.812597	yes

Table 3
The learning process recommended by the original information function for a learner with low ability

Learning iteration	Clicked courseware	Recommended courseware of top 1	Concept relation degree of the clicked courseware with the recommended courseware of top 1	Difficulty parameter of clicked courseware	Difficulty parameter of recommended courseware of top 1	Learner's ability	Do you understand of the clicked courseware ?
1	FOR 迴圈(使用時機) Using opportunity of "for" instruction	continue 語法介紹 Introduction of syntax of "continue" instruction	0.347404	-0.5	0.066666667	-0.2130979	no
2	continue 語法介紹 Introduction of syntax of "continue" instruction	continue 流程圖 Flowchart of "continue" instruction	0.801784	0.066666667	-0.3	-0.2887633	no
3	continue 流程圖 Flowchart of "continue" instruction	break 流程圖 Flowchart of "break" instruction	0.630893	-0.3	-0.3	-0.3895933	no
4	break 流程圖 Flowchart of "break" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.29821	-0.3	-0.5	-0.4661866	no
5	FOR 迴圈(使用時機) Using opportunity of "for" instruction	break 流程圖 Flowchart of "break" instruction	0.29821	-0.5	-0.3	-0.546	no
6	FOR 迴圈(流程說明) Flowchart of "for" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.433289	-0.266666667	-0.5	-0.58957333	no
7	goto 流程圖 Flowchart of "goto" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0	-0.166666667	-0.5	-0.61939	no
8	FOR 迴圈(應用實例一) Example 21of "for" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.448276	-0.1	-0.5	-0.64172	no
9	continue 範例(一) Example 1 of "break" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.198517	0.066666667	-0.5	-0.65512	no
10	while 語法介紹 Introduction of syntax of "while" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.361485	0.1	-0.5	-0.66648333	no
11	do while 流程圖 Flowchart of "do while" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.0958927	0.1	-0.5	-0.67706666	no
12	無窮迴圈範例(一) Example 1 of infinite loop instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.262613	0.1	-0.5	-0.68696333	no
13	goto 語法介紹 Introduction of syntax of "goto" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.0357371	0.1	-0.5	-0.69625333	no
14	break 範例(一) Example 1 of "break" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0	0.133333333	-0.5	-0.70427333	no
15	break 範例(二) Example 2 of "break" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.0830455	0.133333333	-0.5	-0.71188	no

Table 4
The learning process recommended by the original information function for a learner with moderate ability

Learning iteration	Clicked courseware	Recommended courseware of top 1	Concept relation degree of the clicked courseware with the recommended courseware of top 1	Difficulty parameter of clicked courseware	Difficulty parameter of recommended courseware of top 1	Learner's ability	Do you understand of the clicked courseware ?
1	FOR 迴圈(使用時機) Using opportunity of nested loop	continue 語法介紹 Introduction of syntax of "continue" instruction	0.347404	-0.5	0.066666667	0.046716	yes
2	continue 語法介紹 Introduction of syntax of "continue" instruction	無窮迴圈介紹 Introduction of infinite loop instruction	0.46291	0.066666667	0.166666667	0.179688	yes
3	無窮迴圈介紹 Introduction of infinite loop instruction	巢狀迴圈(迴圈定義) Definition of nested loop	0.695379	0.166666667	0.266666667	0.282149667	yes
4	巢狀迴圈(迴圈定義) Definition of nested loop	break 語法介紹 Introduction of syntax of "break" instruction	0.445132	0.266666667	0.166666667	0.187554	no
5	break 語法介紹 Introduction of syntax of "break" instruction	巢狀迴圈(迴圈定義) Definition of nested loop	0.445132	0.166666667	0.266666667	0.26691	yes
6	while 迴圈範例(二) Example 2 of "while" instruction	break 語法介紹 Introduction of syntax of "break" instruction	0.229175	0.3	0.166666667	0.195788333	no
7	do while 語法介紹 Introduction of syntax of "do while" instruction	巢狀迴圈(迴圈定義) Definition of nested loop	0.283197	0.166666667	0.266666667	0.259794	yes
8	continue 範例(二) Example 2 of "continue" instruction	break 語法介紹 Introduction of syntax of "break" instruction	0.181902	0.233333333	0.166666667	0.19594	no
9	FOR 迴圈(迴圈定義) Definition of "for" instruction	goto 範例(一) Example 1 of "goto" instruction	0	0.166666667	0.133333333	0.137708333	no
10	goto 範例(一) Example 1 of "goto" instruction	break 語法介紹 Introduction of syntax of "break" instruction	0	0.133333333	0.166666667	0.188918667	yes
11	do while 迴圈範例(一) Example 1 of "do while" instruction	while 流程圖 Flowchart of "while" instruction	0.5	0.233333333	0.233333333	0.240094667	yes
12	while 流程圖 Flowchart of "while" instruction	巢狀迴圈(應用實例一) Example 1 of nested loop	0	0.233333333	0.3	0.285113333	yes
13	巢狀迴圈(應用實例一) Example 1 of nested loop	while 流程圖 Flowchart of "while" instruction	0	0.3	0.233333333	0.242844333	no
14	break 範例(一) Example 1 of "break" instruction	巢狀迴圈(迴圈定義) Definition of nested loop	0	0.133333333	0.266666667	0.276828	yes
15	無窮迴圈流程圖 Flowchart of infinite loop instruction	巢狀迴圈(應用實例一) Example 1 of nested loop	0	0.366666667	0.3	0.320121667	yes

courseware of top 1 has been learned by learner, then learner will select the recommended courseware of top 2 to do learning, and so on. To analyze the experimental results illustrated in Tables 2–4, we also find that the difficulty parameter of the recommended courseware of top 1 is strongly correlated with learner ability. These results imply that using the original information function can indeed recommend appropriate courseware to learners, according to their abilities. However, we also find that the concept relation degree of the clicked courseware with the recommended courseware of top 1 illustrated in Tables 2–4 is very low for any successive learning process, thus producing overly discontinued learning concept.

3.3.3. *Curriculum sequencing using the modified information function*

To improve the drawback of curriculum sequencing recommended by the original information function, the experiment of learning process recommended by the modified information function is performed to obtain the learning pathway sequences for learners with various abilities. Tables 5–7 illustrate the corresponding learning process recommended by the modified information function for learners with high, low and moderate abilities, respectively. In this experiment, the adjustable weight w for the modified information function is set as 0.6 because we hope to emphasize the importance of concept relation degree. The experimental result shows that the courseware recommended by the modified information function also reserves the advantage recommended by the original information function, which can give appropriate courseware recommendation to learners, according to individual learner ability. Fig. 13 shows the relationship between learner ability and the difficulty parameter of the recommended course material also confirms this fact. In addition, Fig. 14 gives a comparison of concept relation degrees recommended by the original information function with the modified information function. It is very obvious that the recommendation strategy using the modified information function always recommends smoother learning pathways to learners than the original information function. Accordingly, the learning concepts with high concept relation degree will be successively recommended during the learning process under simultaneously considering the learner ability and difficulty levels of courseware. This is very beneficial for learner because it can guide learner to achieve more effective learning.

Finally, to deal with the influence of the parameter of adjustable weight w in the modified information function for curriculum sequencing, Fig.15 shows the plot of relationship between learner ability and the difficulty parameter of the recommended course material, which uses various adjustable weights for courseware recommendation during the learning process. The experimental result shows that the difficulty parameter of the recommended course material is strongly correlated with learner ability if the adjustable

Table 5
The learning process recommended by the modified information function for a learner with high ability

Learning iteration	Clicked courseware	Recommended courseware of top 1	Concept relation degree of the clicked courseware with the recommended courseware of top 1	Difficulty parameter of clicked courseware	Difficulty parameter of recommended courseware of top 1	Learner's ability	Do you understand of the clicked courseware ?
1	FOR 迴圈(使用時機) Using opportunity of "for" instruction	FOR 迴圈(迴圈定義) Definition of "for" instruction	0.714742	-0.5	0.166666667	0.046716	yes
2	FOR 迴圈(迴圈定義) Definition of "for" instruction	無窮迴圈介紹 Introduction of infinite loop instruction	0.527778	0.166666667	0.166666667	0.195154	yes
3	無窮迴圈介紹 Introduction of infinite loop instruction	巢狀迴圈(迴圈定義) Definition of nested loop	0.695379	0.166666667	0.266666667	0.295359	yes
4	巢狀迴圈(迴圈定義) Definition of nested loop	巢狀迴圈(使用時機) Using opportunity of nested loop	0.860946	0.266666667	0.4	0.384133333	yes
5	巢狀迴圈(使用時機) Using opportunity of nested loop	巢狀迴圈(迴圈定義) Definition of nested loop	0.860946	0.4	0.266666667	0.46834	yes
6	無窮迴圈流程圖 Flowchart of infinite loop instruction	無窮迴圈範例(一) Example 1 of infinite loop instruction	0.820244	0.366666667	0.1	0.53219	yes
7	無窮迴圈範例(一) Example 1 of infinite loop instruction	無窮迴圈流程圖 Flowchart of infinite loop instruction	0.820244	0.1	0.366666667	0.564113333	yes
8	FOR 迴圈(應用實例二) Example 2 of "for" instruction	巢狀迴圈(應用實例三) Example 3 of nested loop	0.612372	0.566666667	0.533333333	0.625693333	yes
9	巢狀迴圈(應用實例三) Example 3 of nested loop	FOR 迴圈(應用實例二) Example 2 of nested loop	0.612372	0.533333333	0.566666667	0.673593333	yes
10	巢狀迴圈(應用實例二) Example 2 of nested loop	巢狀迴圈(應用實例一) Example 1 of nested loop	0.92338	0.7	0.3	0.723546667	yes
11	巢狀迴圈(應用實例一) Example 1 of nested loop	巢狀迴圈(應用實例二) Example 2 of nested loop	0.92338	0.3	0.7	0.744033333	yes
12	do while 迴圈範例(二) Example 2 of "do while" instruction	while 迴圈範例(一) Example 1 of "do while" instruction	0.793575	0.366666667	0.4	0.764643333	yes
13	while 迴圈範例(一) Example 1 of "while" instruction	do while 迴圈範例(二) Example 2 of "do while" instruction	0.793575	0.4	0.366666667	0.78389	yes
14	do while 迴圈範例(一) Example 1 of "do while" instruction	while 迴圈範例(一) Example 1 of "while" instruction	0.873326	0.233333333	0.4	0.79566	yes
15	while 迴圈範例(二) Example 2 of "while" instruction	do while 迴圈範例(二) Example 2 of "do while" instruction	0.771517	0.3	0.366666667	0.808096667	yes

Table 6
The learning process recommended by the modified information function for a learner with low ability

Learning iteration	Clicked courseware	Recommended courseware of top 1	Concept relation degree of the clicked courseware with the recommended courseware of top 1	Difficulty parameter of clicked courseware	Difficulty parameter of recommended courseware of top 1	Learner's ability	Do you understand of the clicked courseware ?
1	FOR 迴圈(使用時機) Using opportunity of nested loop	FOR 迴圈(迴圈定義) Definition of "for" instruction	0.714742	-0.5	0.166666667	-0.2130979	no
2	FOR 迴圈(迴圈定義) Definition of "for" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.714742	0.166666667	-0.5	-0.27692	no
3	FOR 迴圈(使用時機) Using opportunity of "for" instruction	FOR 迴圈(流程說明) Flowchart of "for" instruction	0.433289	-0.5	-0.266666667	-0.4068	no
4	FOR 迴圈(流程說明) Flowchart of "for" instruction	FOR 迴圈(使用時機) Using opportunity of "for" instruction	0.433289	-0.266666667	-0.5	-0.47851666	no
5	break 流程圖 Flowchart of "break" instruction	continue 流程圖 Flowchart of "continue" instruction	0.630893	-0.3	-0.3	-0.53775	no
6	continue 流程圖 Flowchart of "continue" instruction	break 流程圖 Flowchart of "break" instruction	0.630893	-0.3	-0.3	-0.58534333	no
7	continue 語法介紹 Introduction of syntax of "continue" instruction	continue 流程圖 Flowchart of "continue" instruction	0.801784	0.066666667	-0.3	-0.60362666	no
8	continue 範例(一) Example 1 of "continue" instruction	continue 流程圖 Flowchart of "continue" instruction	0.534522	0.066666667	-0.3	-0.62009	no
9	continue 範例(二) Example 2 of "continue" instruction	continue 流程圖 Flowchart of "continue" instruction	0.4375	0.233333333	-0.3	-0.62994666	no
10	break 範例(二) Example 2 of "break" instruction	break 流程圖 Flowchart of "break" instruction	0.410391	0.133333333	-0.3	-0.64190333	no
11	break 範例(一) Example 1 of "break" instruction	break 流程圖 Flowchart of "break" instruction	0.324443	0.133333333	-0.3	-0.65302666	no
12	break 語法介紹 Introduction of syntax of "break" instruction	break 流程圖 Flowchart of "break" instruction	0.612056	0.166666667	-0.3	-0.66256333	no
13	FOR 迴圈(應用實例一) Example 21of "for" instruction	FOR 迴圈(應用實例二) Example 2 of "for" instruction	0.928477	-0.1	0.566666667	-0.67982666	no
14	FOR 迴圈(應用實例二) Example 2 of "for" instruction	FOR 迴圈(應用實例一) Example 21of "for" instruction	0.928477	0.566666667	-0.1	-0.68251	no
15	巢狀迴圈(應用實例三) Example 3 of nested loop	FOR 迴圈(應用實例一) Example 21of "for" instruction	0.568574	0.533333333	-0.1	-0.68540666	no

Table 7
The learning process recommended by the modified information function for a learner with moderate ability

Learning iteration	Clicked courseware	Recommended courseware of top 1	Concept relation degree of the clicked courseware with the recommended courseware of top 1	Difficulty parameter of clicked courseware	Difficulty parameter of recommended courseware of top 1	Learner's ability	Do you understand of the clicked courseware ?
1	FOR 迴圈(使用時機) Using opportunity of "for" instruction	FOR 迴圈(迴圈定義) Definition of "for" instruction	0.714742	-0.5	0.166666667	0.046716	yes
2	FOR 迴圈(迴圈定義) Definition of "for" instruction	FOR 迴圈(應用實例一) Example 21of "for" instruction	0.536056	0.166666667	-0.1	-0.04291	no
3	FOR 迴圈(應用實例一) Example 21of "for" instruction	FOR 迴圈(應用實例二) Example 2 of "for" instruction	0.928477	-0.1	0.566666667	0.051566333	yes
4	FOR 迴圈(應用實例二) Example 2 of "for" instruction	FOR 迴圈(應用實例一) Example 1of "for" instruction	0.928477	0.566666667	-0.1	0.013426667	no
5	無窮迴圈範例(一) Example 1 of infinite loop instruction	無窮迴圈介紹 Introduction of infinite loop instruction	0.714435	0.1	0.166666667	0.106581667	yes
6	無窮迴圈介紹 Introduction of infinite loop instruction	無窮迴圈範例(一) Example 1 of infinite loop instruction	0.714435	0.166666667	0.1	0.187735333	yes
7	巢狀迴圈(迴圈定義) Definition of nested loop	無窮迴圈介紹 Introduction of infinite loop instruction	0.695379	0.266666667	0.166666667	0.126432667	no
8	巢狀迴圈(使用時機) Using opportunity of nested loop	巢狀迴圈(迴圈定義) Definition of nested loop	0.860946	0.4	0.266666667	0.086221667	no
9	continue 範例(一) Example 1 of "continue" instruction	continue 語法介紹 Introduction of syntax of "continue" instruction	0.571429	0.066666667	0.066666667	0.026938	no
10	continue 語法介紹 Introduction of syntax of "continue" instruction	continue 範例(一) Example 1 of "continue" instruction	0.571429	0.066666667	0.066666667	0.083548667	yes
11	continue 流程圖 Flowchart of "continue" instruction	continue 語法介紹 Introduction of syntax of "continue" instruction	0.801784	-0.3	0.066666667	0.109104333	yes
12	while 流程圖 Flowchart of "while" instruction	do while 流程圖 Flowchart of "do while" instruction	0.774597	0.233333333	0.1	0.164207667	yes
13	do while 流程圖 Flowchart of "do while" instruction	while 流程圖 Flowchart of "while" instruction	0.774597	0.1	0.233333333	0.204449333	yes
14	do while 語法介紹 Introduction of syntax of "do while" instruction	while 語法介紹 Introduction of syntax of "while" instruction	0.876096	0.166666667	0.1	0.244147	yes
15	while 語法介紹 Introduction of syntax of "while" instruction	do while 語法介紹 Introduction of syntax of "do while" instruction	0.876096	0.1	0.166666667	0.276089	yes

weight *w* is set as a smaller value, but the concept continuity of learning pathway will be negelected. In contrast, the experimental result also shows that the similar learning concepts will be successively recommended during neighboorhood learning process if the adjustable weight *w* is set as a larger value, but the difficulty parameter of the recommended course material will be weakly correlated with learner ability. In this manner, this study suggests that the adjustable weight *w* is set as 0.6 can satisfy the needs of curriculum sequencing and obtain high quality courseware recommendation.

4. Conclusion

This study proposes a personalized Web-based instruction system (PWIS) based on the proposed IRT with modified information function, which can estimate on-line

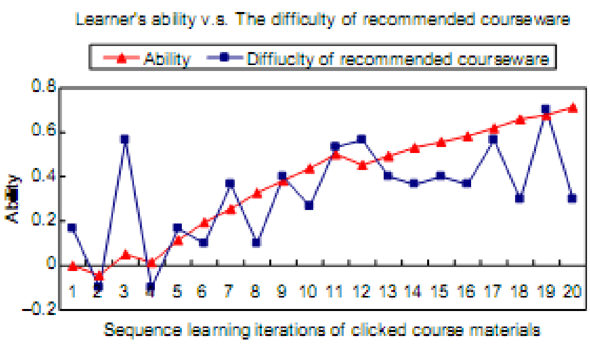

Fig. 13. The relationship between learner's ability and the difficulty parameter of the recommended course material during the learning process (The adjustable weight is set as 0.6).

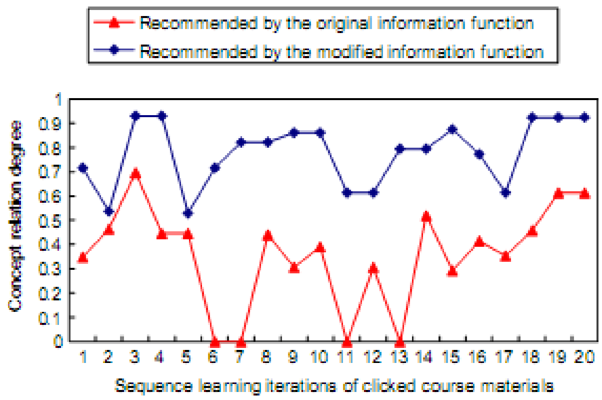

Fig. 14. Comparison of concept relation degrees recommended by the original information function with the modified information function during learning process.

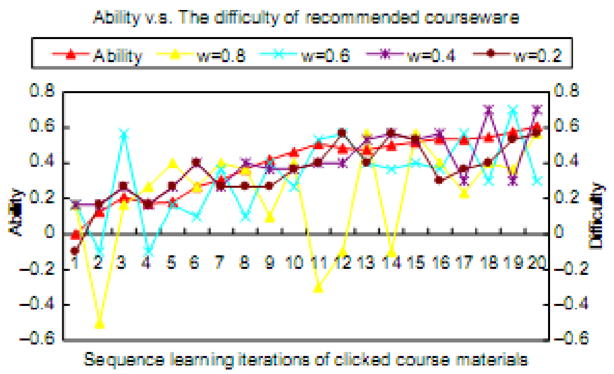

Fig. 15. The relationship between learner's ability and the difficulty parameter of the recommended course material using various adjustable weights during learning process.

the abilities of learners and recommend courseware with appropriate and smoother learning pathways to learners. Compared to the original IRT, the modified IRT can simultaneously consider courseware difficulty level, learner's ability and the concept continuity of successive courseware while implementing personalized curriculum sequencing in learning processes. The PWIS provides personalized Web-based instruction according to courseware visited by learners and their responses. Moreover, courseware difficulty parameters can also be correctly determined by the proposed courseware modeling process. Experimental results indicate that the proposed system can precisely provide personalized curriculum sequencing based on learner abilities and concept continuity of successive courseware, and moreover can accelerate learner's learning effectiveness. Importantly, learners only need to reply to two simple questionnaires for personalized curriculum sequencing. Besides, to provide personalized e-learning services more intimately, our future research will consider some aided learning tools such as personalized learning pathway analysis and diagnosis agents.

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