Applying Knowledge Map to Diagnose Students' Misconception and Provide Suitable Teaching Materials

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Abstract: - Students in the web-based e-learning environment might have their own learning paths due to the structure of the world-wide web. Students can choose suitable learning materials according to their different learning style. There are many researches about learning diagnosis in distance education and the main objective of these researches is to improve the learning effects of students. This research proposes a diagnosis mechanism based on the Knowledge Map and implements a feedback system in order to provide the remedy teaching materials in sequence.

Key-Words: e-Learning, Concept Map, Knowledge Map, Learning Diagnosis, Learning Feedback

1 Introduction

With the growth and development of the computer and Internet, the teaching activities in the Internet are more convenient and popular and called distance learning. In recent years, many researchers mentioned the Computer-Assisted Instruction (CAI) [2] [17] [22]. The purpose of CAI is to assist the teacher to improve the instructions of course, however, it still has a lot of issues which are faced by teachers when they are applying technologies into their courses and classes. Additionally, lots of scholars are devoted to the development of on-line instant feedback test to replace the traditional paper pen test.

Learning process has their gradations, for example step by step or from easy to difficult, every gradation of learning is to prepare for the next gradation and the qualitative changes during the learning process will also happen [18]. In order to facilitate learning effectively, the main principle of adaptive learning is to diagnose students by their answers of the test and arrange the follow-up teaching materials in accordance with the learning achievement of students.

With the purpose of improve the learning effects of students on Internet, the methods of measurement, tracking, and evaluation are used to discover the learning states of students and decide the suitable teaching materials, it is so-called the performance technology of learning [6] [16]. According to Clark and Langdon's opinions, the suitable and effective teaching materials can facilitate learning more effiency. Moreover, interaction is also one of the indispensable characteristics in teaching and the main shaft designed of interaction system on Internet is the test and commenting of achievement [21].

There are two kinds of applications which apply the computer technology to the test [1]: (1) Build and construct a test (2) Use the computer as the media of the examination. The two kinds of applications can be seen as active and passive applications simply. The passive application is always recording the processes, preserving and reporting the statistics and learning results of students [5]. The active application will guide students learning, diagnose the misconceptions, and prevent students from making a mistake.

A good test system not only can assess learning effects of students, but also can diagnose the learning barrier of students and help students to overcome those obstacles. Therefore, a good test system must reach two major objectives: (1) analyzes the basic obstacles of students while they are learning, (2) settles a learning sequence to improve the academic achievement of students. In order to reach these two objectives, this paper applies the knowledge map to the distance learning environment in order to diagnose students' misconceptions and generate the learning sequence of supplemental teaching materials after test. Beside that, the diagnosis mechanism and the feedback system will also make the full-loop learning completely.

The knowledge map incorporates the concept map with concept schema and use for knowledge representation is proposed by Kuo et al. in 2002. In education, the concept map often used to diagnose the learning achievement and the students' mental model [19]. The knowledge map has two advantages: (1) represent the relations between concepts clearly just like the concept map; and, (2) represent the related attributes of concept which are kept in the concept schema.

The problem proposed by this paper is formulated in Section 2, and Section 2 will also describe some research backgrounds such like Concept Map and Knowledge Map on WWW. Section 3 will analyze the diagnosis mechanism and give a complete example. Algorithms of the three-step diagnosis mechanism are designed and the feedback system is also developed in Section 4. In Section 5, the experiment and the evaluation results are discussed. Section 6 makes a simple summary and describes the possible future researches.

2 Concept Map and Knowledge Map

2.1 Definitions of Concept Map

Concept maps are logic-based knowledge representation formalism, whose elements belong either to concepts or relations. The technique was developed by Professor Joseph Novak at the Cornell University in 1960s. Concepts within a designated domain are given as a concept set $C = \{c_i\}$. For example in Chemistry the concept set of elements, $C_{element}$, might be $C_{element}$ = {SUBSTANCE, METAL, NONMETAL, IRON, MERCURY, OXYGEN, SULFUR, ¡-}.

The relation between two concepts, c_i and c_j, can denote as $\rho_k = \{c_i, c_j\}$, where k indicates the specific category in the relation category set and the relation set is $\rho = \{\rho_k\}$. The relation category is also a set, that is, k = {part of, type of, leads to, analogy, characteristic, evidence} according to previous researches [8] [9] [12] or k = {clustering, aggregation, linkage} proposed by Meyer in 1985 and so on. Proposition is usually used to represent the meaning of a sentence, it can correspond to a Boolean value, that is true or false.

A proposition describes the relation between concept could be written as $\phi_i(\rho_k(c_i, c_j, ...)) \rightarrow V = \{true, false\}$. For example, "the ACCELERATION of GRAVITY is 9.8" could be written as

$\phi_i(\rho_{is}(\text{ACCELERATI ON OF GRAVITY}, 9.8)) \rightarrow true$

The knowledge not only can help students to understand the concepts in the specific domain, but also can guide students during the learning process. We can find the misconceptions of the student by diagnosing the change of the concept map which is stored inside the student's mind [10] [13] [15].

2.2 Definitions of Knowledge Map

Knowledge map is a knowledge representation formalism comprising with concept hierarchy and concept schema [14]. Concept hierarchy represents knowledge in a hierarchical way. Collin and Quillian indicated that human organize knowledge in a structure way and store characteristics of the concept in different level of the structure [7]. The concept hierarchy is defined as $CH(C, \rho)$, where C is the concept set and ρ is the relation set. Fig. 1 is a example of concept hierarchy.

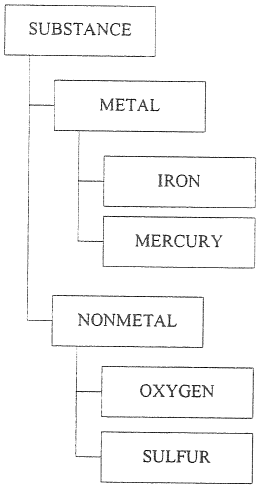


Fig. 1. Concept Hierarchy

In cognitive psychology, schema is used to identify messages from the real world and store the attributes of the message. Schema is a high level knowledge representation formalism integrate with nature, events and text [11]. Concept schema is used to describe the attributes of a concept. The concept schema of a concept set C is defined as: $CS(C) = \{\rho_k(c_i, c_j)\}$. The following Table 1 is the concept schema of elements in the Chemistry domain.

Table 1. Concept Schema

Element Concept Set	Status Concept Set
SUBSTANCE	SOLID
SUBSTANCE	LIQUID
SUBSTANCE	GASSEOUS
METAL	SOLID
METAL	LIQUID

METAL	GASEOUS
.....	.....
OXYGEN	GASEOUS
MERCURY	LIQUID

Once we have the concept hierarchy and the concept schema, a knowledge map for the specific domain (or a concept set) can be integrated as Fig. 2 shown below.

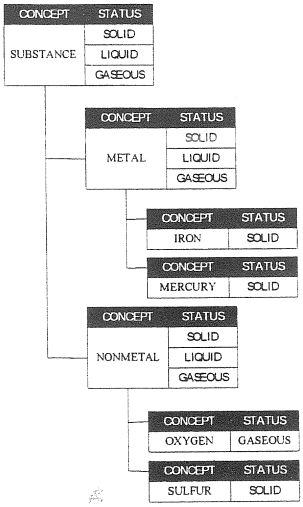


Fig. 2. A Knowledge Map for Specific Domain

3 Learning Diagnosis and Feedback

The purpose of this research is to diagnose the learning achievement of students on the Internet-based learning environment and to offer the suitable learning feedbacks in sequence according the learning achievement. Before the analysis is made, there are three assumptions needed to list for this research.

- ASSUMPTION 1: In the test, student gets the wrong answer of an item means student has missing some relevant concepts in the item.
- ASSUMPTION 2: In the concept hierarchy of knowledge map, the concept in the upper (more abstract) level will involve those concepts in the lower (more specific) level.
- ASSUMPTION 3: When a concept becomes a barrier to the student, the relevant concepts will also become barrier to the student.

In order to find the student's misconception, the teaching materials and test items must be analyzed first. Then student can make test on Internet and the system collect the test result. Finally, system according to the test result and teaching materials selected suitable teaching material for remedy learning and represent as a learning path. The learning diagnosis and feedback step is described below.

3.1 Analysis in teaching materials with knowledge map

According to the knowledge schema and concept hierarchy, the teaching materials could be analyzed and reorganized. After analyzing the teaching materials (web pages), a matrix is created which is called the embedded concept matrix (*ECM*).

Every teaching material, no mater what representation format, contains concepts that related to the course, therefore, the embedded concepts (*EC*) of teaching material can be obtained via analyzing by the domain experts. The association between concept c_i and teaching material d_j is denoted as $EC(c_i, d_j) \in [0,1]$, high value means high association. Embedded concept matrix, $ECM=[EC(c_i, d_j)]$, represents the concept association between documents, and the value of $EC(c_i, d_j)$ is given by expert or calculated by content analysis method. The test items also can be analyzed and found the embedded concept and represent as *ECM* with the same way.

EXAMPLE 1: *CH* and its Matrix (*CHM*)
Given a teaching material set which contains

1. five teaching materials $D = \{d_1, d_2, d_3, d_4, d_5\}$
2. six related concepts $C = \{c_1, c_2, c_3, c_4, c_5, c_6\}$
3. six items $Q = \{q_1, q_2, q_3, q_4, q_5, q_6\}$
4. embedded concept matrix of teaching materials $ECM(C,D)$ (the relations between teaching materials and concepts are analyzed by the expert)
5. embedded concept matrix of items $ECM(C,Q)$ (the relations between item and concepts are analyzed by the expert)
6. the concept relations are $\rho(c_1, c_2)$, $\rho(c_3, c_4)$, $\rho(c_3, c_5)$ and $\rho(c_4, c_6)$.

$$ECM(C,D) = \begin{bmatrix} 0.6 & 0.154 & 0 & 0 & 0.5 \\ 0 & 0.385 & 0 & 0.18 & 0.25 \\ 0.4 & 0 & 0.17 & 0.45 & 0.25 \\ 0 & 0.384 & 0.83 & 0 & 0 \\ 0 & 0.77 & 0 & 0.36 & 0 \\ 0 & 0 & 0 & 0 & 0.9 \end{bmatrix}$$

$$ECM(C,Q)=\begin{bmatrix}1&0&0&0&0&0\\0&0&0&1&0&1\\0&0&1&0&0&0\\0&0&0&0&1&0\\0&1&0&0&0&0\\1&0&0&1&0&0\end{bmatrix}$$

After analyzing the *ECM* and *CH*, the Concept Hierarchy Matrix (*CHM*) could be found out as:

$$CHM=\begin{bmatrix}0&0&0&0&0&0\\1&0&0&0&0&0\\0&0&0&0&0&0\\0&0&1&0&0&0\\0&0&1&0&0&0\\0&0&0&1&0&0\end{bmatrix}$$ □

3.2 Misconception diagnosis via online test

Moreover, since there are association among concepts in both concept map and knowledge map, the cumulative embedded concept is then constructed for representing the concept hierarchy. Also the domain experts (teachers) will take responsibility to assign the concept thresholds and hidden concepts for a test. According to the ASSUMPTION 2 and ASSUMPTION 3, the cumulative embedded concept matrix (*CECM*) is used to introduce the relations between the concepts in the knowledge map by using the original *ECM* matrix and the concept hierarchy. Hence, *CECM* can come from *CHM* and *ECM*, it define as (1) and (2).

$$CHM(C,C)=\lfloor \rho(c_i,c_j) \rfloor, \forall c_i,c_j \in C \quad (1)$$

$$CECM(C,Q)=(CHM(C,C)+I(C))^T \cdot ECM(C,Q) \quad (2)$$

According to *CECM*, the distribution of concepts in all items can be found by (3).

$$DCECM(i,j)=CECM(i,j)/\sum_{j=1} CECM(i,j) \quad (3)$$

EXAMPLE 2: Given a $CHM(C,C)$ in the following, find the cumulative embedded concept matrix, $CECM(C,Q)$, for items and the distribution of concepts, $DCECM(C,Q)$, in all items.

$$CHM(C,C)=\begin{bmatrix}0&0&0&0&0&0\\1&0&0&0&0&0\\0&0&0&0&0&0\\0&0&1&0&0&0\\0&0&1&0&0&0\\0&0&0&1&0&0\end{bmatrix}$$

$$CECM(C,Q)=(CHM(C,C)+I(C))^T \cdot ECM(C,Q)$$

$$=\left(\begin{bmatrix}0&0&0&0&0&0\\1&0&0&0&0&0\\0&0&0&0&0&0\\0&0&1&0&0&0\\0&0&1&0&0&0\\0&0&0&1&0&0\end{bmatrix}+\begin{bmatrix}1&0&0&0&0&0\\0&1&0&0&0&0\\0&0&1&0&0&0\\0&0&0&1&0&0\\0&0&0&0&1&0\\0&0&0&0&0&1\end{bmatrix}\right)^T \cdot \begin{bmatrix}1&0&0&0&0&0\\0&0&0&1&0&1\\0&0&1&0&0&0\\0&0&0&0&1&0\\0&1&0&0&0&0\\1&0&0&1&0&0\end{bmatrix}$$

$$=\begin{bmatrix}1&0&0&1&0&1\\0&0&0&1&0&1\\0&1&1&0&1&0\\1&0&0&1&1&0\\0&1&0&0&0&0\\1&0&0&1&0&0\end{bmatrix}$$

$$DCECM(C,Q)=\begin{bmatrix}0.3333&0&0&0.3333&0&0.3333\\0&0&0&0.5000&0&0.5000\\0&0.3333&0.3333&0&0.3333&0\\0.3333&0&0&0.3333&0.3333&0\\0&1.0000&0&0&0&0\\0.5000&0&0&0.5000&0&0\end{bmatrix}$$ □

3.3 Misconception diagnosis via online test

Once the student completes the test, the misconception diagnosis mechanism can compute the distribution of misconception for the student and judge which concept belongs to misconception according to the threshold. The value of threshold, which is given by the domain expert, is between 0 and 1. Once the misconception value of a student is higher than the threshold, which means the student gets misunderstanding on the correspondent concept.

The first step of the diagnosis process is comparing the *CECM* with the student's answer matrix, $A = \{ a_i \mid a_i \in 0,1 \}$, in test, that is, the value of a_i is 0 if the student's answer is right and a_i=1 if the student's answer is wrong. After that, the misconception degree matrix Φ_S of students can be found from the student answer matrix A and *DCECM* as (4).

$$\Phi_S = A \cdot DCECM^T \quad (4)$$

EXMAPLE 3: Misconception degree of students. Given an answer matrix of five students.

$$A=\begin{matrix}S_1\\S_2\\S_3\\S_4\\S_5\end{matrix}\begin{bmatrix}1&1&0&1&1&1\\1&1&1&0&1&1\\1&0&1&1&0&1\\0&0&1&1&1&1\\0&0&0&0&1&0\end{bmatrix}$$

The misconception degree of each student will be

$$\Phi_S = A \cdot DCECM^T$$

$$= \begin{bmatrix} 1.0000 & 1.0000 & 0.6667 & 1.0000 & 1.0000 & 1.0000 \\ 0.6667 & 0.5000 & 1.0000 & 0.6667 & 1.0000 & 0.50000 \\ 1.0000 & 1.0000 & 0.3333 & 0.6667 & 0 & 1.0000 \\ 0.6667 & 1.0000 & 0.6667 & 0.6667 & 0 & 0.5000 \\ 0 & 0 & 0.3333 & 0.3333 & 0 & 0 \end{bmatrix}$$

□

3.4 Learning sequence generation

The objective of this research is to try and create a learning sequence based on the recommendatory weights of teaching materials. The feature vector for each teaching material will be retrieved at first, and then the similarity between misconception degree of student and *ECM* of teaching material is used for selecting supplemental materials. With the weight order of supplemental materials, a remedy learning sequence will be generated automatically.

The concepts are involved in a teaching material which similar to the students' misconception will be recommended as the supplemental materials. The calculation of similarity is defined as (5).

$$sim(\Phi_S, ECM(C, d_j)) = \frac{\Phi_S \bullet ECM(C, d_j)}{|\Phi_S| \times |ECM(C, d_j)|} \quad (5)$$

According to the threshold of misconception and the students' misconception, the system can select teaching materials for each student as supplemental materials. The learning path in this research is representation in a catalog way and sorted according to similarity. Students can learning sequence suggested by system or selected by themselves.

EXMAPLE 4: The similarity between the misconception of the students and the concept distribution of the teaching materials will be

$$sim(\Phi_S, ECM(C, D)) =$$

$$\begin{array}{c} \\ S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \end{array} \begin{array}{c} \begin{array}{ccccc} d_1 & d_2 & d_3 & d_4 & d_5 \end{array} \\ \begin{bmatrix} 0.5151 & 0.7596 & 0.4772 & 0.5963 & 0.7152 \\ 0.6026 & 0.7514 & 0.4638 & 0.8098 & 0.5780 \\ 0.5393 & 0.4414 & 0.3818 & 0.2899 & 0.8444 \\ 0.5752 & 0.4844 & 0.4896 & 0.4947 & 0.6859 \\ 0.3922 & 0.2843 & 0.8346 & 0.5270 & 0.1624 \end{bmatrix} \end{array}$$

□

EXMAPLE 5: The selected teaching materials for each student should be [final step]

Assume the the domain expert designates a threshold, 0.5, for example.

$s_1 = \{d_1, d_2, d_4, d_5\}$

$s_2 = \{d_1, d_2, d_4, d_5\}$

$s_3 = \{d_1, d_5\}$

$s_4 = \{d_1, d_5\}$

$s_5 = \{d_3\}$. □

4 System Design and Measurement

In this research, the supplemental teaching materials are selected by similarity and the hierarchical order of teaching materials. The purpose of this research is to format the contents in webpages dynamically according to the different misconceptions of students.

4.1 Algorithms and System Archiecture

Base on the analysis in previous Section, the system architecture is shown in Figure 3. As Figure 3 illustrates, before the diagnosis can be done the materials should be taken into the knowledge analysis first as the Prev. 1 and Prev. 2 steps in Figure 3. After that, the embedded concept matrix of materials will be constructed and can be used to support the similarity calculation (step 4 in Figure 3). Beside the materials, the items in the test will be also needed to analyze for figuring out its embedded concepts. Once the cumulative embedded concepts in each items of the test are figured out (Test 1 to Test 3 steps), it can be used to diagnose the misconception of the student who took the test.

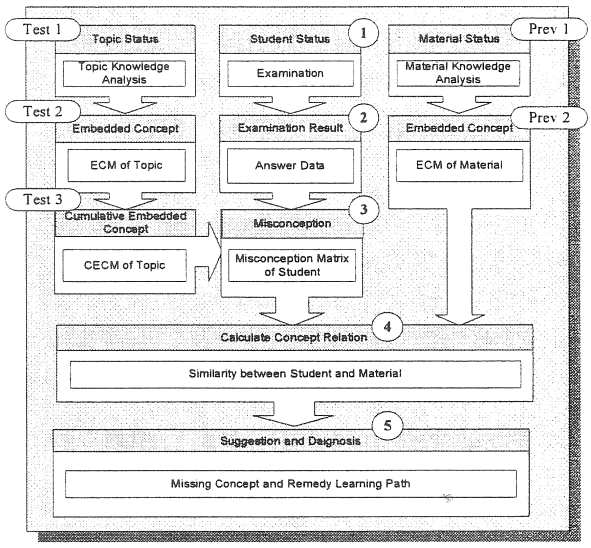


Fig 3. System Architecture

The system collects and records the learning process and the result of examination. When the student logon the system, the system starts to record the learning process of the student and the examination results after each test (step 1and 2 in Figure 3) for analyzing the learning effect of the student. After analyzing the collected data (step 3), the system will recommend suitable teaching materials by comparing the similarity of the answer sheet and the concept distribution of teaching materials (step 4 and step 5). After diagnosing, the system will suggest suitable teaching materials as feedback according to the examination results. In

order to evaluate the feedback is really suitable and useful for students, the measurement is also designed as following.

4.2 Measurement Method

This paper uses the terms of statistics includes the Precision, the Recall, and the F-measure, as the measurement of evaluating the effects of recommendatory materials [20]. The Precision (P), the Recall (R), and the F-measure (F) between concepts in the misconception t and the teaching material c are:

$$P_{c,t} = \frac{N_t \cap N_c}{N_c} \tag{6}$$

$$R_{c,t} = \frac{N_t \cap N_c}{N_t} \tag{7}$$

$$F_{c,t} = \frac{2}{\frac{1}{P_{c,t}} + \frac{1}{R_{c,t}}} \tag{8}$$

The evaluation methodology takes the percentage of recommendation errors, that are, the Type I error and the Type II error as Table 2 listed below. In statistics, the Type I error means the retrieved data is neither expected nor full covered and the Type II error means the retrieved data is more than needs. Therefore, in this work the Type I error is happened when the system provides some concepts that belongs to the student's misconception but there are no corresponding teaching materials; and, the Type II error is occurred when the system provides some concepts that there are corresponding teaching materials but do not the student's misconception.

Table 2. Error Type

	CONCEPT IN RECOMMENDATORY TEACHING MATERIAL	CONCEPT NOT IN RECOMMENDATORY TEACHING MATERIAL
CONCEPT BELONGS TO STUDENT'S MISCONCEPTION	CORRECT	Type I error (assume true)
CONCEPT NOT BELONGS TO STUDENT'S MISCONCEPTION	Type II error (assume false)	CORRECT

5 Experiment and Results

The experiment was done with the database course in the Dept. of Information and Computer Engineering, Chung-Yuan Christian University. There were 42 students participated this experiment, there were 2 graduate students, 15 senior students and 25 junior students among the participators.

5.1 Experiment Environment

This system is an online test and all topics are in the multiple choice form. A student can do the test anytime after he/she logon the system. When the student finished a test, the system will calculate the student's score; store the test results into database; and, discover the student's misconceptions. The student can find out his/her misconceptions by checking the test results and reading the exposition of each topic. Figure 4 is snapshot of the test and Figure 5 is the test result.

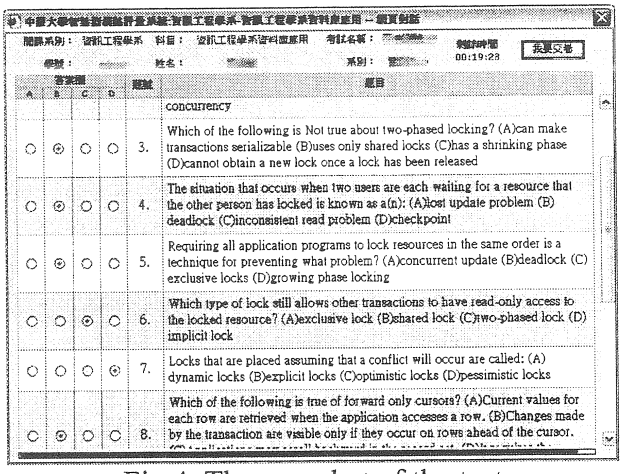


Fig 4. The snapshot of the test



Fig. 5 The snapshot of the test result

After the diagnosis process of misconception is completed, the system selects the suitable teaching materials for remedy learning according to the test results. The student can do remedy learning to correct his/her misconceptions by click the link of remedy teaching materials. Figure 6 shows the diagnosis results and the learning feedbacks.

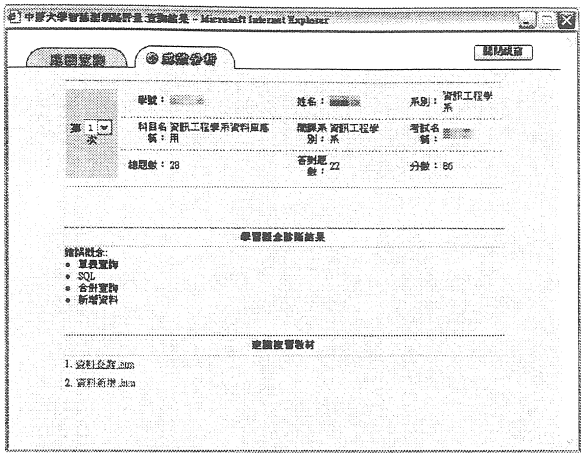


Fig. 6 Diagnosis result and learning feedback

5.2 Experiment Result

The average value of Precision, Recall and F-measure is 0.8569, 0.9255 and 0.8868. The evaluation results showed that the recommendatory teaching materials are suitable for remedying the misconception of the students. Table 3 is the evaluation results of all students.

Table 3. Evaluation Results of the Experiment

ID	1	2	3	4	5	6	7	8	9	10
P-value	0.8333	0.8889	0.875	0.8	0.8571	0.8	1	1	0.9	0.8571
R-value	1	1	0.875	0.8889	1	0.8889	0.6667	1	1	1
F-value	0.9091	0.9412	0.875	0.8421	0.9231	0.8421	0.8	1	0.9474	0.9231
ID	11	12	13	14	15	16	17	18	19	20
P-value	0.8333	1	0.8333	0.8571	0.8182	0.8333	0.8333	0.8	0.8889	0.9
R-value	0.9091	1	0.9091	1	1	0.9091	0.8333	1	1	0.9
F-value	0.8696	1	0.8696	0.9231	0.9	0.8696	0.8333	0.8889	0.9412	0.9
ID	21	22	23	24	25	26	27	28	29	30
P-value	0.8333	0.75	0.875	0.8333	0.75	0.8	0.8889	0.8	0.9286	0.8182
R-value	1	0.8571	0.875	1	0.75	1	0.8889	0.8	1	0.9
F-value	0.9091	0.8	0.875	0.9091	0.75	0.8889	0.8889	0.8	0.963	0.8571
ID	31	32	33	34	35	36	37	38	39	40
P-value	0.8571	1	0.8182	0.9167	0.8182	0.7778	0.8182	0.9	0.8	0.8333
R-value	0.8571	0.8	1	1	0.9	0.875	1	1	1	0.7143
F-value	0.8571	0.8889	0.9	0.9565	0.8571	0.8235	0.9	0.9474	0.8889	0.7692
ID	41	42	Average							
P-value	0.8889	0.875	**0.8569**							
R-value	1	0.875	**0.9255**							
F-value	0.9412	0.875	**0.8868**							

In this experiment, the Type I error, α, is the misunderstanding concepts of student but have not included in suggested materials. When the P-value = 1 and the R-value < 1, the Type I error occurs. Similarly, the Type II error, β, is there are some concepts in suggested materials not belongs to the misconception of students. When the R-value = 1 and the P-value < 1, the Type II error happens. In the statistical hypothesis the value of Type I error should be lower than 0.05 and the value of Type II should be also lower than 0.2.

The Type I error, α, in this experiment is 0.0476, it is quite low and it means the selected teaching materials can cover all concepts for the teaching course. Because in the experiment, the teaching materials can not cover all concepts of the examination, the α would be reduced if the teaching materials could cover every concepts of test. The Type II error, β, in this experiment is 0.4524 which is greater than 0.2. The reason causes the value is so high is because the each unit of teaching materials in this experiment contains too many concepts. If the teaching materials could be subdivided furthermore, the Type II error might be reduced.

6 Conclusion

Different student has different knowledge, learning states and learning achievement in the Internet-based learning environment. The diagnosis mechanism is designed in this work and used to provide sequential remedy materials based on the adaptive learning according to students' answers of test. After this experiment, the evaluation of the recommendatory teaching materials has been made. The evaluation results are good but also reveal some limits. The limits are: (1) students do not follow the learning sequence which generated by the system, although the system is an adaptive system; (2) students do not interest in the Internet-based learning. Beside the limits, there are also some further researches should be done: (1) the system should also analyze the learning effect of the student after repeatedly learning; (2) the system should be able to provide feedback to the teacher in order to let the teacher changes his/her teaching strategies; and, (3) the system should be able to discover a more useful learning sequence based on the theories of traversal pattern and learning path.

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