Diagnostic and remedial learning strategy based on conceptual graphs

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Abstract
Numerous scholars have applied conceptual graphs for explanatory purposes. This study devised the ‘Remedial-Instruction Decisive path (RID path)’ algorithm for diagnosing individual student learning situation. This study focuses on conceptual graphs. According to the concepts learned by students and the weight values of relations among these concepts, this study established the remedial-instruction paths to identify their real missing concepts. This study applies diagnostic and remedial learning strategies to two courses – ‘Introduction and Implementation of RS-232’ and ‘Electronic Circuits Laboratory’. By analysing the scores of the midterm and final exams, evaluations of remedial learning yield positive experimental results. Participants who adopt the diagnostic and remedial learning strategy have better academic performance.

Key words
conceptual graph, Internet, IT-use, remedial instruction, tutorial

Introduction
In online distance learning environments, the Internet is the major medium for communication between instructors and learners. Most of this communication takes the form of online chatting, and in some cases video conferences. The methods most frequently used by instructors to understand the situation of learners are setting homework or examinations. However, these methods do not provide instructors with immediate feedback, and the feedback obtained inevitably lags behind teaching progress. The lack of face-to-face interaction between instructors and learners in on-line distance learning makes it difficult for instructors to know the situation of learners, and this weakness must be improved. By recording and analysing learner behaviour, details of individual learning situation can be obtained, including progress, strengths and weaknesses. Furthermore, a system can be designed to automatically generate a series of aided-learning contents for every student.

The Intelligent Tutoring System (ITS) is a learning system that provides learning suggestions or plans according learner behaviour and performance. Koe-dinger and Anderson (1997) developed an ITS for algebra problem solving, named the system PAT. This ITS monitored learner performance in the background of learning activities using two modelling techniques: model tracing and knowledge tracing. Virvou et al. (2000) proposed an intelligent tutoring system for Greek students studying the passive voice in English. Their study focused on identifying student behaviour by identifying the characteristics of student errors, then classified errors into several categories and supported the helpful suggestions.

The ‘Conceptual graph’ (Sowa 1976; Novak & Goin 1984) is another traditional assisted teaching method. A conceptual graph is composed of propositions defined by two concept nodes and one connecting relation link. The concept nodes are arranged in a hierarchical structure. The ‘Conceptual graph’ method displays knowledge structures. Teachers can use the conceptual graph to determine student comprehension
levels for specific knowledge themes. For this reason, many scholars have been performing research on conceptual graphs (Goldsmith et al. 1991; Bowen & Kocura 1993; McClure et al. 1999).

Conceptual graphs have two main applications. The first application is concept mapping, in which students must configure concept maps by themselves. Diagnoses are made by comparing the concept maps of each student with those of the instructor (McClure et al. 1999; Ruiz-Primo et al. 2001; Schau et al. 2001; Tsai et al. 2001). The second application is diagnostic conceptual graph. This application does not require students to configure individual conceptual graphs, and instead the instructor makes a single conceptual graph. The learning situation of each student is evaluated using the pre-defined conceptual graph to produce their diagnostic conceptual graphs. Diagnostic conceptual graphs guide the instructor to focus on areas where the students need to improve (Hwang 2002).

Hwang (1998, 2002) designed a computer-assisted diagnostic system that includes concept–effect relationships. The concept–effect relationship is a set of association levels that represents the relationship between each concept node and each test item. In Hwang’s research, the instructor must set an association level for each relationship before the course begins. According to the answers of students, the algorithm could obtain student learning information with each concept node. The existence of $m$ concepts and $n$ test items is assumed. The instructor then must focus on $m \times n$ association levels. Generally, a learning topic includes approximately 10–20 concepts and over 200 test items. Maintaining numerous association levels is difficult. To eliminate these difficulties, this study develops a novel strategy embedded in a computer-assisted system for diagnosing student learning situations. This study designed an online learning system with the proposed strategy. After students login to the learning server via the Internet, the system constantly monitors student behaviour to produce learning portfolios for storage in the database server. The learning portfolios of each student include learning duration, login frequency, Q&A, discussion content, homework, and statistical data. These learning portfolios enable relevant concepts that students have failed to understand to be obtained, and enable the automatic building of a dynamic remedial-instruction path.

For diagnosing the learning result of each concept, the Sequential Probability Radio Test (SPRT) (Wald 1947) is used to determine whether the students have mastered certain concepts (Frick 1989). SPRT is used to determine the probability of a student having the right answers and to determine student mastery of concepts. SPRT is an assessment examination model based on Bayes’ rules for predicting student proficiency ratio. SPRT is a variable-length mastery test, which differs from a fixed-length mastery test. The diagnosis process is stopped according to the regulation of SPRT. SPRT is gradually used because it is easy to use and there is no need to adjust the question accuracy (Chung & Wang 2001). Thus this study applied SPRT to diagnose student learning outcome. Based on the diagnostic results of SPRT, this study can identify the weakness of the learning concepts, referred to herein as ‘missing concepts’, which are missing concepts in the complete conceptual graph. The following section describes the role of SPRT in this study.

This study proposes a web-based remedial instruction learning strategy to help teachers manage student learning status in large classes. Teachers can obtain individual student information, and include it with their progress, missing concepts, and faults. This strategy is more convenient than alternatives because it does not require teachers to handle the complex progress of diagnostic and remedial instruction. Teachers only have to set the conceptual graph and choose the learning materials and items.

**Conceptual graph evaluation**

The ‘Concept Map’ traditionally is used as follows: first, students design their concept maps on white paper, and then compare their concept maps with an expert-produced concept map. An environment must be provided in which students can freely construct their concept maps. Students have difficulty in designing their concept maps unaided (Chang et al. 2001). This study adopts the basic idea of using the conceptual graph as a learning tool to represent the knowledge structure.

The conceptual graph is a direct and finite connected graph, which comprises a set of concept nodes that indicates student study activities and a set of relationships. A relationship connects two distinct concept nodes. The relationship represents the order of
study, and it named the ‘Epistemological Order’ (Polya 1957). Each epistemological order includes two concepts and a labelled line illustrating their relationship. Moreover, the ‘Epistemological Order’ represents concept-learning order. Consider the ‘Epistemologically Prior’ (EP) type of Fig. 1a, blocks A and B represent two concept nodes in this figure. Moreover, the arrow linking A and B is called the ‘link’, and indicates the epistemological order of A and B. Each link contains a weighted value that represents the degree of correlation between the two concepts. In this study, \( W_{ij} \) presents the degree of correlation between concept \( c_j \) and its prior-concept \( c_i \), and its value represents the strength of the correlation between these two concepts. Furthermore, value of \( w \) is a unit of the adjustment of the weighted value \( W_{ij} \), and consequently is set by the teacher/specialist on a per case basis. Fig. 1a showed that concept A must be learnt before concept B, and has an assigned \( W_{ij} = 0.3 \). Restated, concept A is a prior-concept of concept B and the correlation value between the two is 0.3. For the second type, known as ‘Epistemologically Equal’ (EQ), the dotted line between C and D is termed the ‘cross-link’, and demonstrates that these two concepts display a high correlation in learning activities. The learning outcome of each of these concepts thus affects the other to a certain degree (Chen & Xia 1999).

Weight \( W_{ij} \) can be first determined by experts, or can be preset to be equal for each concept, and the system can automatically calculate the answering result of every student and dynamically adjust the value of \( W_{ij} \). If the study of \( c_j \) and its prior-concept \( c_i \) both are missing concepts, the weight value is changed to \( W_{ij}+nw \), and \( n \) denotes the number of the prior-concept of \( c_j \). Moreover, all the weight values between \( c_j \) and its prior-concepts are decreased by \( w \) to guarantee that the sum of all the weight values between \( c_j \) and its prior-concepts is 1. The weight value then can be adjusted based on actual student learning status.

Notably, it is meaningless to either use a single value of correlation or to compare two values of \( W_{ij} \) and \( W_{mn} \). Comparing the correlation values between prior-concepts can identify the degree of correlation. From Fig 1b, both concepts B and C are prior-concepts of concept A. Thus \( W_{CA} \), with a value of 0.7, can be said to be larger than \( W_{BA} \), with a value of 0.3. The above condition means that, for concept A, concept C is more effective than concept B in learning activities.

When using conceptual graphs for remedy studies, teaching purpose of each concept must be established and student understanding of the content must be clarified. This study used the multi-choice questioning method. Observation of student answers is used to measure student understanding of the concept. This approach can verify the degree of student understanding of the concept, and also can determine student knowledge acquisition regarding this concept.

SPRT calculates the probability that the student has the correct answer (Frick 1989). The formula of SPRT is presented below:

\[
P_r = P_m \frac{P_m^x(1 - P_m)^w}{P_n \frac{P_n}{P_n}(1 - P_n)^w} ,
\]

where \( P_r \) is the probability that the student has the right answer, \( P_m \) the probability that the student has acquired mastery before testing, \( P_n \) the probability that the student has acquired non-mastery before testing, \( P_{nc} \) the probability that the student has acquired mastery and answers correctly, \( P_{nc} \) the probability that the student has acquired non-mastery and answers correctly, \( r \) the number of correct answers and \( w \) the number of incorrect answers.

The formula is used to determine whether the student has mastered the concept. The determining rule is as follows.

1. If \( P_r \geq (1 - \beta)/\alpha \), then declare mastery and terminate the process.
2. If \( P_r \leq \beta/(1 - \alpha) \), then declare non-mastery and terminate the process.
3. If \( \beta/(1 - \alpha) < P_r < (1 - \beta)/\alpha \), then continue the process.

Here \( \alpha \) represents the probability that the student is incorrectly identified as having mastery and \( \beta \) represents the probability that the student is incorrectly identified as having non-mastery.
SPRT is used in the proposed system because it is easy to use and there is no need to adjust the accuracy of the questions. Moreover, SPRT is extremely suitable for the proposed system, since the concepts involved are not complicated, and the testing items are all associated to certain concepts. SPRT can be used to determine whether a learner has mastered a concept by asking a few questions, and increases the accuracy of the test results of the conceptual graph.

In analysing student learning outcomes, this study attempts to identify and transfer the numerical score to the labelled score. Traditional examinations include only two results, correct and incorrect. This arrangement is insufficient for remedial instruction. The main focus of the diagnosis in the proposed system is on student learning status, and test score is unimportant. Thus, the dichotomy method is unsuitable.

From the SPRT test outcome, this study classifies the numerical score into three levels: pass concept node, fail concept node, and partial concept node.

1. **Pass node**: The student has mastered the concept represented by the node, that is the student is proficient in the concept.

2. **Fail node**: The student has not mastered the concept represented by the node, that is the student is not proficient in the concept. The concept is assumed to be a concept that the student is missing.

3. **Partial node**: The limited questions cannot judge the proficiency of the student. The student may have partially understood the teaching material. Thus, the student should continue learning.

**Diagnostic and remedial learning strategy**

This study proposed and developed a Remedial-Instruction Decisive path (RID path) to diagnose individual student learning situation. The RID path systematically guides study activities. The system analyses the current learning status of each student and then determines their study processes. Student learns concepts under the planned process. Study outcomes are stored in an evaluated conceptual graph, and the evaluated conceptual graph representing the learning patterns, which include the concepts of learning failure and success held by each student. According to the evaluated conceptual graph, the system can modify future student study processes directly, and can provide suitable material to assist each student. The above process is repeated until the student completes their conceptual study in the RID path stage (Wu et al. 2002).

The algorithm of the RID path finds a remedial-instruction decisive path based on missing concepts using SPRT. When a certain student is assessed to have failed to achieve mastery of a certain concept, \( c_j \), their prior-concepts of that student can be obtained. These concepts are tested to identify the missing prior-concepts. The algorithm repeats the diagnosis steps for each missing prior-concept. Numerous missing concept nodes may be found, and may be located on different sub-paths with endings at \( c_j \).

Figure 2 shows an example of an algorithm for finding the RID path. The algorithm includes a test stack containing some concepts that are awaiting examination. Concepts that are missing concepts for students must be examined. On beginning their learning activities, students have an empty evaluated conceptual graph and test stack (step A). The learning activities begin with a starting concept that may be either selected by the student or suggested by the instructors (step B). After finishing the concept-related learning activities, students are tested using the SPRT (step C).

According to the `Epistemologically Order`, if the student identifies that concept 8 is a missing concept then some prior-concepts must also be missing. Therefore, this study assesses the prior-concepts of concept 8 in order of decreasing weight value. For a test order, all prior-concepts are placed in a test stack in increasing order of weight value (step C). The next step pops the topmost concept from test stack, and thus concept 6 is selected as the next test concept (step D). If concept 6 is also identified as a missing concept, the correlation between concepts 6 and 8 is increased. To indicate this diagnostic situation, the weight values between concept 8 and its other prior-concepts are decreased, while the weight values between concepts 6 and 8 are increased by the sum of these decreased values. In this case, the value of \( w \) is assumed to be 0.01 (the instructor can adjust this value independently in the proposed system). The weight value between concepts 7 and 8 thus is reduced by 0.01, while the weight value between concepts 6 and 8 is increased by 0.01 (step E).

Following a series of evaluations, missing concepts that the student failed to master in the learning activities are identified. These missing concepts are distributed over the evaluated conceptual graph, and
are connected by a series of lines (step M). The system also tests concepts 3 and 7 before step N. The RID path can be determined once all of the missing concepts are identified. The first step in building the RID path is to push concept 8 into the test stack. All of the prior-concepts for concept 8 that are missing then can be pushed into the stack in increasing order of weight. This operation is repeated until the stack includes all

Fig. 2 Example of building a RID path.

path is to push concept 8 into the test stack. All of the prior-concepts for concept 8 that are missing then can be pushed into the stack in increasing order of weight. This operation is repeated until the stack includes all
of the missing concepts (step N). Finally, all of the missing concepts are popped to form the RID path. In this case, the RID path is concept 2 → concept 1 → concept 4 → concept 6 → concept 8 (step O). In the proposed system, each student has a unique RID path. This arrangement facilitates student re-learning of any missing concepts.

Consider Fig. 3 in the diagnosis process; SPRT judges student learning result and student learns following the RID path proposed by the system. After finishing their learning and diagnosis activities, students can see and interpret the outcome of the evaluated conceptual graph they have learned. Student interest in related themes will vary with their level of study motivation. The evaluated conceptual graph shows the distribution of well-learned concepts and less well-learned concepts with their own local characteristics. The evaluated conceptual graph produced after a student finishes a learning procedure can represent their learning situation and help in establishing a learning model. This outcome can demonstrate student understanding of different concepts. The evaluated conceptual graph of all of students also implies a conceptual graph of a class, which has different weight values to the conceptual graph of a specialist that contains the original weight values. The conceptual graph of a class includes the adjusted weight values that show the class learning situation. Compared with traditional examination methods, the proposed system can obtain more information about a student’s understanding of different concepts. This information includes a conceptual graph of a class that represents the learning status of all students.

Owing to differences between rural and urban families, the student learning situation represents various learning outcomes. Compared with the conceptual graph of a specialist and a class, the proposed approach can determine the weakness of different classes, and then can notify teachers to arrange further curricular structures as appropriate. Compared with the traditional lecture method, the proposed system can make automatic adjustments depending on the RID path at any time, then allowing the learning to fit the real learning situation of students in different cases. The algorithm employed is useful, effective, and accurate for classroom structures.

**Web-based remedial instruction system**

This study designed a web-based remedial instruction system with the proposed strategy, and conducted two evaluations on this platform. Figure 4 shows the system architecture.

Three main components of this system are described as follows:

1. **User interface**: For convenience, teachers do not need to handle student learning progress in diagnostic and remedial instruction. Teachers only need to set the parameters of the conceptual graph and select the learning material and items. The parameters of the conceptual graph include $W_{ij}$, the set of weight values of the concept link and adjusted unit $w$.

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![Diagram](image_url)
2 Learning-related database: The proposed system includes four main databases: item bank, teaching material, the conceptual graph of a specialist and evaluated conceptual graphs. A specialist conceptual graph presents the structure and learning sequence of a single course topic. The conceptual graph of a specialist remains unchanged in the learning activities. Each concept node in the conceptual graph contains teaching material and test items. In the learning activities, the student must complete the test of each concept node using the SPRT. The evaluated conceptual graph records the test results of each concept node. Each student thus has a unique evaluated conceptual graph that maps their knowledge structure.

3 Remedial instruction module: Student learning outcomes are identified using the item bank database and SPRT. This study presents a ‘RID path’ strategy to identify the missing concepts of students and guiding their learning.

Figure 5 illustrates the framework of the proposed evaluation method. Student learning situations can be diagnosed using the conceptual graph. The evaluated conceptual graph representing student knowledge structure can be obtained from the data in the conceptual graph and the student SPRT results. Each student has a unique evaluated conceptual graph indicating their learning outcomes.

Assessment and discussion

Two evaluations were performed to evaluate the performance of the proposed diagnostic and remedial learning strategy. One evaluation was conducted in March 2001, while the other was conducted in October 2003. Both evaluations were performed at the Department of Information and Computer Engineering, Chung Yuan Christian University in Taiwan. The first evaluation was a pilot study examining the usability and acceptability of the proposed algorithm. The algorithm and procedures were refined, and then another evaluation conducted two years after the pilot study comprised the main study.

Evaluated course

The pilot study course was entitled ‘Introduction and Implementation of RS-232’. This course was one part of the course ‘Operating System’ taught to the junior class. The course ‘Introduction and Implementation of RS-232’ introduced the theorem and function of RS-232, an area that is a separate subject concerned with constructing conceptual graphs. On completing the course, students had to implement a programme for transmitting messages via RS-232. Figure 6 shows the evaluation screen.

The course name of the main study was ‘Electronic Circuits Laboratory’ and taught in the sophomore class. This course introduced electronic devices and instruments used in circuits, and provided students with opportunities to implement circuit theory. This course familiarized students with basic theories and virtual circuits.

Evaluation participants

A pilot study included 38 junior students, while the main study included 80 sophomores. All of the study participants had experience of using computers and the Internet.

Evaluation plan

All participants took a pre-test before each evaluation. The participants were randomly divided into two
categories, and these two categories were ensured to have an equal degree with ANOVA using the pre-test score. The experimental group in the pilot study included nineteen participants, and the remaining participants were assigned to the control group. In the main study, 40 participants were included in each group. The participants logged into the system via network connections.

In the evaluation activities, all participants had to receive instruction from the course instructor and finish their assignments. Moreover, in extracurricular activities, both the control and experimental groups logged in to the system and completed some review tests before taking the next course. The different learning arrangements between the two groups are the learning-guide method. The RID paths guided the progress of the experimental group members. Moreover, the members of the control group learned by their plan. Upon completing all of their learning activities, participants took a post-test.

Evaluation result of the pilot study

This experiment divided the students into experimental and control groups. Table 1 lists the relationship between the pre- and post-test results.

Because the experimental and control groups were randomly grouped following the pre-test, together with some adjustments, Table 1 lists that there was no significant difference between the pre-test for the two categories (the average score of the experimental group was 11.68, with standard deviation 1.76; the average score of the control group was 11.58, with standard deviation 1.46).

The ANOVA was adopted to identify the post-test relationship between the experimental and control groups ($\alpha = 0.05$). The two groups were found to differ significantly in terms of post-test results ($F_{95(1,36)} = 4.71$), and the average score of the experimental group (9.74) was higher than that of the control group (8.37). Consequently, after finishing the remedial instruction activities, the experimental group can be said to perform better than the control group.

Evaluation result of the main study

This experiment also divided the students into experimental and control groups. Table 2 lists the relationship between the pre-test and post-test results for the two groups.

Table 2 reveals no significant difference in the pre-test results for the two categories (the average score for the experimental group was 8.5, with standard deviation 0.13, while that for the control group was 8.58, with standard deviation 0.32).

Another ANOVA test was used for identifying the post-test relationship between the experimental and control groups.

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<th>Table 1. Summary table of pre- and post-test (pilot study)</th>
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control groups \((z = 0.05)\). This test found a significant difference between the two groups in terms of the post-test results \((F_{95(1,78)} = 4.59)\), and the average score of the experimental group (69.88) was higher than that of the control group (63.8). The experimental group thus performs better than the control group.

**Conclusion and future work**

In large classes, teachers have little time to consider the learning status of every individual student. Consequently, the fast-learning students rapidly grasp the subject material, while the slow-learning students fall behind and often are ultimately forgotten by the education system. This study proposes an RID path algorithm based on a conceptual graph to diagnose and analyse student missing concepts. Students who learn these missing concepts using the present study guide and remedial-instruction paths can learn easily and effectively. To analyse the effect of the proposed strategy, two courses were evaluated, namely, ‘Introduction and Implementation of RS-232’ and ‘Electronic Circuits Laboratory’. Following a pilot evaluation, this study first refines the proposed system and procedures, and then performs a main evaluation; both evaluations produced positive experimental results that the participants who adopt the proposed strategy have better learning performance.

Future works will continue to improve the remedial learning strategy. According to the evaluation records, the remedial learning is helpful to numerous students, but provides insufficient help for very slow-learning students. Very slow-learning students cannot keep up with the learning process by themselves, even when aided in identifying various missing concepts. This study focused on individual learning, but interaction among learners also requires improvement. Future works then can improve upon the strategy to support cooperative learning activities. Each team member simultaneously helps slow-learning students and guides them by the proposed online remedial system.

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