Technology-Enhanced Learning in Science, Technology, and Mathematics Education: Results on Supporting Student Learning

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Abstract

To prepare students to be creative and lifelong learning individuals in a rapid growth in science, technology, and mathematics (STM), technology in education plays an important role for enhancing learning performance. In the recent years, researchers have demonstrated the pivotal influences of technological personalized learning environments based on the concept-effect relationship model on student learning performance improvement. Such learning environment has been demonstrated to be useful for helping teachers to diagnose learning problems for individual students according to test answers, and to provide personalized remedial learning guidance for improving students’ learning performance. Teachers can also use the knowledge gained from this system to choose learning materials that are appropriate for personalized student. To show effectiveness of technological personalized learning environments based on the concept-effect relationship model, this paper presents the results on supporting student conceptual learning in several areas such as mathematics, science, and computer science. Moreover, the guideline for researchers/practitioners is also presented at the end of this paper.

Keywords: Adaptive learning, e-learning, testing and diagnostic system, concept-effect relationships, STM education;

1. Introduction

With the rapid growth of science, technology, and mathematics (STM), learning environment is needed to prepare for promoting students to be creative and lifelong leaning individually. Computers and communication technologies have been one way to overcome the need of this preparation. In the recent years, consequently, computers and communication technologies play an important role for enhancing learning performance and more focus on personalized learning environment (Chen, 2008; Chen, 2011; Seters, Ossevoort, Tramper, & Goedhart, 2012; Srisawasdi, Sriakasee, & Panjaburee, 2012). From this view, several researchers have attempted to models/approaches/algorithms including Genetic Algorithm, Fuzzy Logic, Clustering technique, and concept-effect relationship model to diagnose student’s conceptual learning problems and generate corresponding the supplementary material for individual students, accordingly. (Bai & Chen, 2008; Cheng, Lin, Chen, & Heh, 2005; Kaburlasos, Marinagi, & Tsoukalas, 2008; Panjaburee, Hwang, Triampo, & Shih, 2010).

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Among existing models/approaches/algorithms, the concept-effect relationship model have been widely applied in several areas and several levels. For example, Hui Chun Chu, Hwang, Tseng, & Hwang (Chu, Hwang, Tseng, & Hwang, 2006) presented a learning diagnosis approach based on the concept effect model for providing students with personalized learning suggestions by analyzing their test results and test item related concepts. Based on their approach, a testing and diagnosis system was implemented on computer networks. Experimental results on a nutrition course have demonstrated the feasibility of this approach in enhancing students in their learning performance. Jong, Chan, and Wu (Jong, Chan, & Wu, 2007) developed a learning behavior diagnosis system which was applied to a computer course of a university and yielded positive experimental results for both learning status and learning achievement. In the meantime, Tseng et al. (Tseng, Sue, Su, Weng, & Tsai, 2007) employed this model to provide useful learning guidance for individual students in the physics course of a junior high school. Furthermore, Hwang et al. (Hwang, Tseng, & Hwang, 2008) reported the effectiveness of this model in improving the learning achievements of students in a Mathematics course of an elementary school. Clearly, this model has been applied widely to successfully detect the learning problems of students and to give personalized suggestions for several fields, including Natural Science, Mathematics, Physics, Electronic Engineering, and Health courses; moreover for several levels, including, elementary school student, high school student, and undergraduate student.

These studies concluded the results in the same way that personalized learning environment linked with the testing and diagnostic system based on the concept-effect relationship model is useful tool to diagnose learning problems for individual students according to test answers, and to provide personalized remedial learning guidance for improving students’ learning performance. In the following sections, we will show the procedures of diagnosing conceptual learning problems based on the concept-effect relationship model and the relevant experiment study results in several education levels. Moreover, the guideline for researchers/practitioners is also presented at the end of this paper.

2. Review of the concept-effect relationship model

In 2003, Hwang proposed the concept effect relationship (CER) model to diagnose students’ learning problems and provide personalized learning guidance (Hwang, 2003) on intelligent tutoring system. The concept effect relationship is a concept map-oriented approach in which learning sequence relationships indicate the effect of learning one prerequisite concept on the learning of other more complex and higher level concepts. For example, to learn the concept “Multiplication”, one might need to learn “Addition” first; before learning the concept “Division”, one might need to learn “Multiplication” and “Subtraction”. Such learning sequence relationships can be represented as a concept effect relationship as shown in Figure 1.

![Figure 1. An illustrative example of the concept effect relationship](image-url)
When concept effect relations are identified, it is possible to determine the learning problems of each student and provide learning guidance for individual students by tracing the concept effect relationships. For example, if a student is found to have a learning problem during learning concept “Prime numbers” due to a lack of understanding of the questions posed or because of carelessness, the concept “Prime Number” does not represent that the student does not understand the concept “Prime Number” at all; it is very probably that the student has not completely understand a part of concept “Prime Number” only. That is, it may be because the student learned the prerequisite concept (“Division of integers”) incomplete. Therefore, the concept “Division of integers” may be the misconception of this student. In this case, we would suggest that the student study concept “Division of integers” more thoroughly before attempting concept “Prime numbers”. Therefore, teachers could identify the learning problems of students by tracing the concept effect relationships.

To provide learning suggestions to individual students, the error ratio (ER) for each student to answer the test items related to each concept needs to be analyzed; therefore, it is necessary to establish a Test Item Relationship Table (TIRT), which represents the degree of association between test item Qi and concept Ck (Hwang, 2003). An illustrative example of a TIRT comprising ten concepts and ten test items is listed in Table 1., where the TIRT (Qi, Ck) is a value ranging from 0 to 1; “1” represents “high relevance” and “0” represents “no relevance”. The error ratio (ER) for a student for concept Ci is then calculated by dividing the sum of TIRT (Qi, Ck) values of the test items that the student failed to correctly answer by that of all of the test items.

Table 1. Illustrative example of a Test Item Relationship Table (TIRT)

<table>
<thead>
<tr>
<th>Test item Qt</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q2</td>
<td>0</td>
<td>0.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q3</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q4</td>
<td>0</td>
<td>0.4</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.3</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>Q5</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Assuming that ER for a student to answer the test items concerning C1, C2, C3, C4, and C5 are 0.0, 0.25, 0.35, 0.2, and 0.6 respectively, we have:

PATH1: C1 (0.0) → C2 (0.25) → C3 (0.35) → C5 (0.6) and
PATH2: C1 (0.0) → C2 (0.25) → C4 (0.2) → C5 (0.6).

A threshold \( \theta \) is used to determine the acceptable error ratio. If \( \text{ER}(C_j) \geq \theta \), the student is said to have learned concept Cj; otherwise, the student has failed to learn the concept, and it is selected as a node of the poorly-learned path. Assuming that the teacher has defined \( \theta \) to be 0.3, the poorly-learned paths are as follows:

PATH1: C3 (0.35) → C5 (0.6) and
PATH2: C5 (0.6).

Therefore, the learning problems of the student could be a misunderstanding of concepts C3 and C5; moreover, the student should learn C3 before learning C5.

3. Examples of CER model-based implementation

According to the usefulness of concept-effect relationship (CER) model, it could be applied to all education levels including elementary, secondary, and higher education levels in several areas (e.g. natural science, mathematics, computer science). In this section, thus, we will show results of technological personalized learning environment linked with testing and diagnostic system based on the CER model.

3.1 Elementary education level

Hwang developed an intelligent tutoring system based on the CER model to promote elementary school students on topic natural science course taught from September 2001 to December 2001 in Taiwan (Hwang, 2003). There were sixty equivalent students participated in his study. Those students were divided into two groups (i.e., control group and experimental group) by thirty students in each group. The students in control group received regular on-
line tutoring system in which the system did not provide any learning guidance meaning that the students in this group did not know their own conceptual learning problem after each testing on the topic. In the other hand, those in experimental group participated in tutoring system based on the CER model in which this system gave them personalized information after each testing such as learning status of each concept related to topic natural science, learning guidance for improving their own learning problems, and corresponding homework. After finishing the topic, the post-test results showed that the students in experimental group had significant better score than those in control group. It implied that the elementary students who learned in an intelligent tutoring system based on the CER model could improve their learning progress on the topic.

3.2 Secondary education level

Regarding it is necessary to establish the degree of association between test item and related concepts in the CER model, Panjaburee et al., in 2010, proposed a multi-expert approach to integrate such degree given by multiple experts/ domain to making high quality degree of association between test item and related concepts. The integrated degree was used to be input in a testing and diagnostic learning problem (TDLP) system which was developed basing upon the concept of CER model. Panjaburee et al. (2010) evaluated the effectiveness of their system on mathematics course for topic “System of Linear Equation” with 113 secondary school students in Thailand. Three teachers with fifteen experienced teaching on the topic were domain experts in this study. The participating students, thus, were divided into 4 groups (i.e., three control groups and one experimental group). Students in control groups were asked to participate in TDLP linked with the degree of association between test item and related concepts given by single expert, while those in experimental group were asked to involve in TDLP linked with the degree of association between test item and related concepts given by multiple experts. All students were asked to log on the online system to take a pre-test. The system analyzed their answers, provided the learning performance level of each concept related to the topic, guided the way to improve their own learning problems, and gave supplementary homework in paper-based format accordingly. We could see that the students in control group 1, 2, and 3 received those personalized information given by domain expert 1, 2, and 3, respectively, and those in experimental group received the information from integrated opinion of these three domain experts. After experiencing corresponding homework, all students took a post-test to compare learning achievement among four groups. This study showed that students in experimental group performed significant better that those in control groups. Finally, Panjaburee et al. mentioned that a multi-expert approach could help students improved learning achievement after experiencing in a TDLP based on the CER model.

Similarly, regarding CER serves as a tool for tracing conceptual learning problems, Hwang et al., in 2012, proposed a group decision approach to integrate CER from multiple experts/ domain to making high quality CER. The integrated CER was used to be input in a testing and diagnostic system which was developed basing upon the concept of CER model. Hwang et al. (2012) evaluated the effectiveness of their system on mathematics course for topic “Computations and Applications of Quadratic Equations” with 104 secondary school students in Taiwan. Three teachers with four experienced teaching on the topic were domain experts in this study. The participating students, thus, were divided into 4 groups (i.e., three control groups and one experimental group). Students in control groups were asked to participate in a testing and diagnostic system linked with the CER given by single expert, while those in experimental group were asked to involve in a testing and diagnostic system linked with the CER given by multiple experts. After taking a pre-test, the students in three control groups received learning suggestions based on the CER given by domain expert 1, 2, and 3, respectively, while those in experimental group received learning guidance followed by the CER from integrated opinion of three experts. The system then provided supplementary material related with personalized conceptual learning suggestions. After finishing learning activities, all students took a post-test. The post-test results showed that there was significant different score between the low-achieved students in experimental group and those in three control groups. Hwang et al. concluded that a group decision of multiple experts could help students improved learning achievement after experiencing in a personalized learning material based on the CER model.
3.3 Higher education level

Because the integration of weighting values is an important issue for developing testing and diagnostic systems based on the CER model. Therefore, Dechawut, in 2012, attempted to propose a majority density based method to enhance integration of opinion from multiple experts. His method considers the degree of confidence in making the decision about the weighting value, the majority opinion, and the reliability of the integrated weighting value. It provides a useful way to integrate the weighting values while developing testing and diagnostic systems based on the CER model. He claimed that it would make high quality weight value resulting high quality learning suggestion given by testing and diagnostic systems. He compared the effectiveness of his method with Panjaburee et al (2010) method by conducting an experiment on a Computer programming course for undergraduate students in Thailand. The results reveal that students in the experimental group, using a testing and diagnostic learning system constructed by his method, could get significantly better performance than those in the control group, using Panjaburee et al (2010) method. Moreover, he found that the participating students were satisfied with the conceptual learning guidance and would recommend the system to other students for improving the learning outcome.

To sum up results from these three education level, we found that the use of CER model (i.e., step 1 constructing CER, step 2 presetting intensity of test item and related concepts, step 3 calculating incorrect answer ratio, and step 4 tracing learning problem based on CER) could help students to aware of their conceptual learning problems, improve their concept learning ability based on the given corresponding learning materials. We suggest that the application of CER model could be benefit for developing testing and diagnostic system linked with personalized technology-enhanced learning. Moreover, it could be helpful for students in all levels including elementary, secondary, and higher education levels. However, when applying the CER model, there are several factors need to be taken into account such as constructing CER by single or multiple experts and presetting intensity of test item and related concepts by single or multiple experts.

References