Computers & Education 55 (2010) 527–540

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

A multi-expert approach for developing testing and diagnostic systems based on the concept-effect model

Patcharin Panjaburee [a], Gwo-Jen Hwang [b], Wannapong Triampo [c,*], Bo-Ying Shih [b]

[a] Institute for Innovative Learning, Mahidol University, 999, Phuttamonthon 4 Road, Salaya, Nakorn Pathom 73170, Thailand
[b] Department of Information and Learning Technology, National University of Tainan 33, Sec. 2, Shulin St., Tainan city 70005, ROC, Taiwan
[c] Department of Physics, Faculty of Science, Mahidol University, Rama VI, Bangkok 10400, Thailand

ARTICLE INFO

Article history:
Received 24 August 2009
Received in revised form
11 February 2010
Accepted 11 February 2010

Keywords:
Computer-based testing
Computer-assisted learning
Concept-effect relationships
Multiple expert systems

ABSTRACT

With the popularization of computer and communication technologies, researchers have attempted to develop computer-assisted testing and diagnostic systems to help students improve their learning performance on the Internet. In developing a diagnostic system for detecting students' learning problems, it is difficult for individual teachers to address the exact relationships between the test items and the concepts. To cope with this problem, this study proposes an innovative approach to eliciting and integrating the weightings of test item-concept relationships from multiple experts. Based on the proposed approach, a testing and diagnostic system has been implemented; moreover, an experiment was conducted to evaluate the performance of our approach. By analyzing the results from four groups of students using learning suggestions provided by different models, it was found that the learning performance of the students who received learning suggestions by applying the innovative approach was significantly better than for those who received guidance based on the original model.

1. Background and motivation

With the popularization of computers and communication technologies, information as well as instructional activities has been located on the Internet. Notable examples include the development of computer-assisted tutoring and testing systems (Chiou, Hwang, & Tseng, 2009; Hooper, 1992; Hwang, Cheng, Chu, Tseng, & Hwang, 2007; Hwang, Chu, Yin, & Lin, 2008; Hwang, Yang, Tsai, & Yang, 2009; Lee, Lee, & Leu, 2009; Plessis, Biljon, Tolmie, & Wollinger, 1995; Springer & Pear, 2008; Tsai & Chou, 2002; Tseng, Chu, Hwang, & Tsai, 2008). Specifically, during the tutoring process, online evaluation becomes an important form of learning feedback to provide the learning status of each student, and tests are mostly used as a way to gain this knowledge (Gronlund, 2003; Hwang et al., 2007; Tsai & Chou, 2002). In the past decades, researchers have shown the equivalence of paper-based and computer-based tests in terms of testing quality, implying that the development of computer-based testing systems and relevant techniques are worthwhile (Chiou et al., 2009; Hwang, 2003b; Hwang, Chu, et al., 2008).

Conventional testing systems represent the learning status of a student by assigning a total score or grade. Such feedback makes the students aware of their learning status through the score or grade; however, this information alone is insufficient for improving their learning performance unless further guidance can be given (Gerber, Grund, & Grote, 2008). This implies that providing learning suggestions for students after testing is an important research issue (Hwang, Tseng, & Hwang, 2008).

In recent years, researchers have proposed various approaches for developing adaptive learning systems based on the personal features or learning behaviors of students (Casamayor, Amandi, & Campo, 2009; Cheng, Lin, Chen, & Heh, 2005; Huang, Liu, Chu, & Cheng, 2007; Hwang, Tsai, Tsai, & Tseng, 2008; Manning & Dix, 2008; Offer & Bos, 2009). Furthermore, models or mechanisms for diagnosing student learning problems and providing personalized learning guidance have been presented as well (Bai & Chen, 2008; Huang, Lin, & Cheng, 2009; Hwang, Hsiao, & Tseng, 2003; Lee et al., 2009; Pavlekovic, Zekic-Susac, & Djurdjevic, 2009; Tseng, Sue, Su, Weng, & Tsai, 2007; Tung, Huang, Keh, & Wai, 2009). Among the existing models, the Concept-Effect Relationship (CER) model, which represents the prerequisite relationships among concepts in a course, has been proved to be an effective way of improving the learning performance of students (Hwang,

* Corresponding author. Tel.: +668 40042689; fax: +662 441 9322.
E-mail addresses: panjaburee_p@hotmail.com (P. Panjaburee), gjhwang@mail.nutn.edu.tw (G.-J. Hwang), wtriampo@gmail.com, scwtr@mahidol.ac.th (W. Triampo), shallmay14@gmail.com (B.-Y. Shih).

0360-1315/$ – see front matter
doi:10.1016/j.compedu.2010.02.015

2003a). The CER model demonstrates a systematic procedure for identifying the learning problems of students for each concept taken into account. It has been used to successfully detect the learning problems of students and to give personalized suggestions to them for several science and mathematics courses (Hwang et al., 2007; Hwang, Tseng, et al., 2008; Jong, Lin, Wu, & Chan, 2004).

Although the CER model has shown its effectiveness in helping students improve their learning performance, past experiences of applying this model also reveal the difficulty of applying it. One of the major problems of applying the CER model is the need to define the weighting or degree of relevance for each concept to each test item. It is often the case that individual teachers might provide some imprecise <test item, concept> relationships owing to ignorance or subjectivity or unintentionally inconsistent decision making (Hwang, Tseng, et al., 2008; Lee et al., 2009); moreover, researchers have indicated that domain experts with different experiences could have different expertise or understanding of each portion of the knowledge; therefore, the cooperation of several experts (experienced teachers) has been suggested (Chu & Hwang, 2008; Huang & Shimizu, 2006; Hwang, Chen, Hwang, & Chu, 2006; Léger & Naud, 2009; Medsker, Tan, & Turban, 1995; Mittal & Dym, 1985). As the experts might have different experiences and domain knowledge or backgrounds, it becomes an important and challenging issue to integrate the opinions of multiple experts to obtain high quality <test item, concept> relationships such that more accurate and truthful learning suggestions can be given to the students (Chu & Hwang, 2008).

To cope with this problem, this paper presents an innovative approach by integrating <test item, concept> relationships from multiple experts. Moreover, a testing and diagnostic system based on this approach has been implemented, and an experiment was conducted to evaluate the performance of the innovative approach.

2. The concept-effect relationship (CER) model

Hwang (2003a) proposed the CER model to represent the prerequisite relationships among concepts that need to be learned in a dedicated order. Such a model has been referred to by several researchers in developing testing and diagnostic mechanisms or systems for improving the learning performance of students. Moreover, various applications have revealed the effectiveness of the CER model. For example, Jong, Chan, and 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. (2007) employed the CER model to provide learning guidance for individual students in the physics course of a junior high school. Furthermore, Hwang, Tseng, et al. (2008) reported the effectiveness of the CER model in improving the learning achievements of students in a Mathematics course of an elementary school.

In the CER model, the diagnosis of student learning problems mainly depends on the prerequisite relationships between the concepts to be learned. Consider two concepts to be learned, say C_i and C_j. If C_i is a prerequisite to efficiently performing the more complex and higher level concept C_j, then a concept-effect relationship $C_i \rightarrow C_j$ is said to exist. For example, to learn the concept “subtraction of positive integer,” one may first need to learn “addition of positive integer”, while learning “division of positive integer” may require first learning “subtraction of positive integer” and “multiplication of positive integer”. Fig. 1 presents an illustrative example of the concept-effect relationships, which are important in diagnosing student learning problems. For example, if a student fails to answer most of the test items concerning “division of positive integer” due to a lack of understanding of the questions posed or because of carelessness, the problem is likely because the student has not thoroughly learned “division of positive integer” or its prerequisite concepts (such as “subtraction of positive integer” or “multiplication of positive integer”). Therefore, teachers could identify the learning problems of students by tracing the concept-effect relationships (Cheng et al., 2005; Hwang, 2003a; Hwang, Tseng, et al., 2008).

In the CER model, all of the possible learning paths will be taken into consideration to find the poorly-learned paths. In the illustrative example given in Fig. 1, there are two learning paths for the subject unit:

$$\text{PATH1} : C_1 \rightarrow C_2 \rightarrow C_3 \rightarrow C_5$$

$$\text{PATH2} : C_1 \rightarrow C_2 \rightarrow C_4 \rightarrow C_5$$

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 Q_i and concept C_k (Hwang, 2003a). An illustrative example of a TIRT comprising ten concepts and twelve test items is listed in Table 1, where the TIRT (Q_i, C_k) is a value ranging from 0 to 1; “1” represents “high relevance” and “0” represents “no

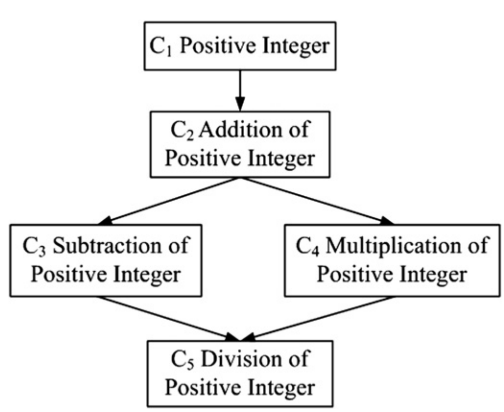

Fig. 1. Illustrative example of concept-effect relationships.