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Development of a diagnostic system using a testing-based approach for strengthening student prior knowledge

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ABSTRACT

Students learn new instructions well by building on relevant prior knowledge, as it affects how instructors and students interact with the learning materials. Moreover, studies have found that good prior knowledge can enable students to attain better learning motivation, comprehension, and performance. This suggests it is important to assist students in obtaining the relevant prior knowledge, as this can enable them to engage meaningfully with the learning materials. Tests are often used to help instructors assess students' prior knowledge. Nevertheless, conventional testing approaches usually assign only a score to each student, and this may mean that students are unable to realize their own individual weaknesses. To address this problem, instructors can diagnose the test results to provide more detailed information to each student, but this is obviously a time-consuming process. Therefore, this study proposes a testing-based diagnosis system to assist instructors and students in diagnosing and strengthening prior knowledge before new instruction is undertaken. Furthermore, an experiment was conducted to evaluate the effectiveness of the proposed approach in an interdisciplinary course, since several studies have indicated that students learn more and better in such courses when applying relevant prior knowledge to what they are learning. The experimental results show that the developed system is able to effectively diagnose students' prior knowledge and enhance their learning motivation and performance on an interdisciplinary course. In addition, two diagnostic evaluations were also conducted to assess whether the diagnoses given by the system were consistent with the decisions of experts. The results demonstrate that the proposed system can effectively assist instructors and students in diagnosing and strengthening prior knowledge before new instruction is undertaken, since the diagnoses produced by the system were broadly consistent with those of experts.

1. Introduction

Diagnosing and strengthening students' prior knowledge is an important task before teaching and learning new knowledge or skills, because prior knowledge affects how instructors and students interact with the learning materials they encounter (Moos & Azevedo, 2008; Ozuru, Dempsey, & McNamara, 2009). From the view of instructors, students' prior knowledge often confounds their best efforts to deliver instructions accurately (Roschelle, 1995). Moreover, it also affects how instructors plan their teaching strategies for new instructions in order to enhance students' learning motivation and performance (Biswas, 2007; Seel & Dinter, 1995). On the other hand, with regard to students, if they do not have good and relevant prior knowledge, then there is a strong risk that they may build new knowledge on faulty foundations (Dochy, Moerkerke, & Marten, 1996). In addition, based on psychologists' investigations, good prior knowledge can help learning because memory or mental storage capacity can be developed through association with pre-existing knowledge (Clarke, Ayres, & Sweller, 2005; Cobos-Moyano, Martin-Blas, & Oñate-Gómez, 2009; Liu & Andre, 2006). Furthermore, studies have indicated that good prior knowledge can enhance students' motivation, comprehension, and performance with regard to learning new knowledge or skills (Jong & Joolingen, 1998; Mitchell, Chen, & Macredie, 2005; Moreno, 2004; Yates & Chandler, 1994; Zhang, Zhao, Zhou, & Nunamaker, 2004). In addition, prior knowledge is a key to learning new information, catalyzing it, and then applying it to other contexts (Cohen & Levinthal, 1990).

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As mentioned above, this suggests it is important to diagnose and strengthen students' prior knowledge so that they are able to engage meaningfully with new learning materials. In general, tests are used to assess student understanding (Panjaburee, Hwang, Triampo, & Shih, 2010; Treagust, 1988). In the past two decades, computer-based testing systems have been widely developed and adopted to assess knowledge levels, because they can provide a more intelligent and convenient environment than is possible with paper-and-pencil tests (Cheng, Huang, Chen, & Lin, 2005; Cheng, Lin, & Huang, 2009; Huang, Lin, & Cheng, 2009). However, in terms of testing quality, researchers have found that paper-and-pencil and computer-based tests are equivalent (Chiou, Hwang, & Tseng, 2009; Hwang, 2003b; Hwang, Chu, Yin, & Lin, 2008). Nevertheless, in both forms conventional testing systems usually assign only a score or grade to instructors and students, and thus both groups may be unable to immediately and accurately realize what gaps or weaknesses may exist in the latter's prior knowledge (Gerber, Grund, & Grote, 2008). To address this problem, instructors can diagnose the testing results to provide additional guidance to assist each student in strengthening the relevant prior knowledge. However, this is a time-consuming task, because there are often many students taking a course, especially in higher education.

Therefore, to assist instructors in diagnosing and strengthening students' prior knowledge before new instructions and to enable students to attain greater learning motivation and improved learning performance, a testing-based diagnosis system is proposed in this study to cope with these problems. Moreover, an experiment is conducted on an interdisciplinary course, namely bioinformatics, at a university in Taiwan to investigate the effectiveness of the proposed approach, because several studies have indicated that students learn more and better in an interdisciplinary course when they apply relevant prior knowledge to what they are learning (Czerniak, Weber, & Sandmann, 1999; Keedwell & Narayanan, 2005; Kelemen, Abraham, & Chen, 2008; Lavnitskaya, Clark, Montgomery, & Primean, 2002). In addition, two diagnostic evaluations were also conducted to examine the accuracy of diagnoses derived from the proposed system.

The remainder of this paper is organized as follows. Section 2 describes the methodology developed in this study, and an example is given to demonstrate the proposed approach. The architecture and implementation of system is presented in Section 3. The experiment and results evaluation are shown in Sections 4 and 5, respectively. Section 6 presents the evaluation of the diagnoses produced by the proposed system. Finally, the conclusions, discussions, and suggestions for further research are presented in Section 7.

2. Methodology

To measure the strength of understanding of prior knowledge, a prior knowledge diagnosis (PKD) model is proposed. In order to describe the PKD model in detail, this section is organized into two sub-sections to depict the methodology of the PKD model and provide an illustrative example.

2.1. PKD model

The PKD model uses two data sources. The first is the testing information assigned by teachers, and this represents a relationship between each concept and test item in a test, and the relationships among the concepts. The second is derived from students, and represents a relationship between their answers and the test items.

Assume that a teacher instructs a subject of a course and he or she specifies n concepts, $C_1, C_2, C_3,\ldots, C_i,\ldots C_m,\ldots, C_n$ that are the prior knowledge of the subject for r participating students, $S_1, S_2, S_3,\ldots, S_l,\ldots, S_r$. According to the criteria, the PKD model can pick out relevant test items from a test item bank for the teacher. Following that, the teacher can select the needed test items to form a pre-test before teaching the subject. Suppose that the teacher applies personal expertise to select k test items, $I_1, I_2, I_3,\ldots, I_j,\ldots, I_k$ from the test item bank to form the pre-test, with k test items that are relevant to one to n concepts. In addition, each concept is possibly related to the others. The teacher then conducts the pre-test to assess the understanding strength of the r students on the n concepts using the PKD model to diagnose the students' prior knowledge.

To represent the degree of relevance between each concept and test item, an X-value is used. X_{mj} indicates the degree of relevance between the mth concept and the jth test item. In this study, the relevance is rated on a scale from 0 to 1.

In addition, to represent the relationship between the concepts, a Z-value is adopted that also ranged from 0 to 1. Z_{im} indicates the relationship between the ith and the mth concepts.

Based on the X and Z values, the strength of concept C_i in the pre-test can be measured as:

$$S(C_i) = \sum_{m=1}^{n}\sum_{j=1}^{k} Z_{im}X_{mj} \quad (1)$$

where $S(C_i)$ represents the strength of concept C_i in the pre-test, $0 \le S(C_i) \le nk$; Z_{im} represents the relationship between the ith and the mth concepts, $0 \le Z_{im} \le 1$; and X_{mj} indicates the degree of relevance between the mth concept and the jth test item, $0 \le X_{mj} \le 1$.

From Eq. (1), it can be seen that the strength of a concept is influenced by the degree of relevance between the concept and all the other test items, and also by the relationship between the concept and other concepts.

Moreover, based on the X and Z values, the importance ratio of concept C_i in the pre-test can be measured as:

$$IRP(C_i) = \frac{\sum_{m=1}^{n}\sum_{j=1}^{k} Z_{im}X_{mj}}{\sum_{i=1}^{n}\sum_{m=1}^{n}\sum_{j=1}^{k} Z_{im}X_{mj}} \quad (2)$$

where IRP(C_i) represents the importance ratio of concept C_i in the pre-test, $0 \le \mathrm{IRP}(C_i) \le 1$; Z_{im} represents the relationship between the ith and mth concepts, $0 \le Z_{im} \le 1$; and X_{mj} indicates the relevance degree between the mth concept and the jth test item, $0 \le X_{mj} \le 1$.

The two measurements of concept can be used to determine the effects of each concept on the subject. Therefore, based on the information of the test items in the pre-test, the PKD model can infer the strength and importance ratio of each concept.

After the r students have taken the pre-test, their test results for each test item can be recorded. To represent the relationship between students' answers and test items, an R-value is adopted using a binary coding scheme. R_{lj} indicates the answer of the lth student on the jth test item. If the student answers the test item correctly, R_{lj} is 1; otherwise R_{lj} is 0.