

How to Construct an Assessment System for Engineering Courses

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Abstract: Most test items used for engineering courses are application problems with a serial of calculations and logical adjustments. Mistakes of the parent (front) calculations may inherit to their child (rear) calculations. Teachers spend too much time in administering the examination. Therefore, the purpose of this article is to specify how to design and construct an assessment system with partial credit function for the engineering courses. Applying concept-mapping technique along with Petri-Nets and Goldsmith's closeness index theory, this system can inferential diagnoses in order to investigate examinee's misconceptions and produce the reasonable scoring for engineering courses.

Keywords: Computer-assisted assessment, Partial credit, Petri-nets

1. Introduction

Learning and teaching engineering in university level is not an easy job, since the knowledge structure on engineering is complex and may not be well defined. Therefore, it becomes a challenge or probably inappropriate to use the traditional tests, such as multiple-choice, fill-in-blank, or short essay type questions for assessing students' achievement. Most traditional tests are dichotomously scoring that fail to detect the thinking process of how students solve the problems. Instead, they only reflect students' response in last step. Such a traditional test ignores the importance of student's problem-solving performance in multiple steps, and neither provides the analysis of students' misconceptions in the process. In contrast to the dichotomously scoring, the polytonality scoring instruments are able to provide more accurate and valid assessment in engineering courses (Muraki, 1992, p. 160). Therefore, most engineering faculty in university favors the polytonality tests. However, there are some limitations for using the polytonality tests. First, they have to be administered manually, and take much more time. Second, teachers are still hard to describe students' misconceptions due to the limitation of teachers' memory. Therefore, the purpose of this research is to specify how to design and develop an assessment system to meet the needs of tests and measurements in the engineering courses. Three useful designed tactics are adopted in this research. First, the concept mapping technique is used as the format of reply sub-system. Second, a rule-based Petri-net module representing the logic structure of correct answer is proposed. Third, the fuzzy mapping technique is used to calculate the score of test and diagnose students' misconceptions.

The proposal assessment system includes the following functions and features:

- (1) This assessment system holds a dynamical parameter function, which can change the numeric components of items randomly, to prevent students from memorizing the answers (Hwang, 2003). The test items are changed automatically by following the adjustment of test concepts.
- (2) The concept mapping is used for representing the examinee's answers. Concept mapping is the technique of drawing a concept map to illustrate the structure of knowledge. There are some applications of the concept mapping techniques in education, such as the assessment and diagnosis of learning effect, the analysis of the learning path, and the representation of knowledge (Anderson, 1995). Examinee must draw the concept map and answer the calculation results for the testing topic. By using the concept mapping technique, it is easy to obtain enough information to investigate examinee's misunderstandings and to inference for diagnosis (Laffey & Singer, 1997, p. 368).

- (3) The Petri-Nets have been developed to describe information-processing systems that are characterized as being concurrent, asynchronous, distributed, parallel and stochastic (Molloy, 1989). It is adequate to generate test items dynamically, and has many advantages for representing the calculating structure of the testing concepts.

By using the Goldsmith's closeness index (Goldsmith, Johnson & Acton, 1991, p. 92), a calculating logic is developed for the scoring and diagnosis. This article demonstrates the proposed assessment system, not only can give student's grade fairly, but also can make the inference to examine examinee's misconceptions. This proposal system can be a useful tool to assist teacher's teaching and student's practice.

2. System Design

In this section, the system design is described and a test subject (rectangular reinforced concrete beam analysis with single layer bar, Reinforced Concrete, Civil Engineering) is selected to explain the designed procedures for developing this assessment system. The diagram of calculating procedures for selecting subject is shown in Figure 1. The general testing item is: Derive the nominal flexural resisting moment (M_n) of a rectangular RC beam with single layer bar. The given parameters are yield strength of reinforcement (f_y), compressive strength of concrete (f'_c), width of rectangular beam (b), area of tension reinforcement (A_s) and effective depth of rectangular beam (d). Three types of beams (balanced section, over-reinforced section and under-reinforced section) can be identified (Nawy, 1996).

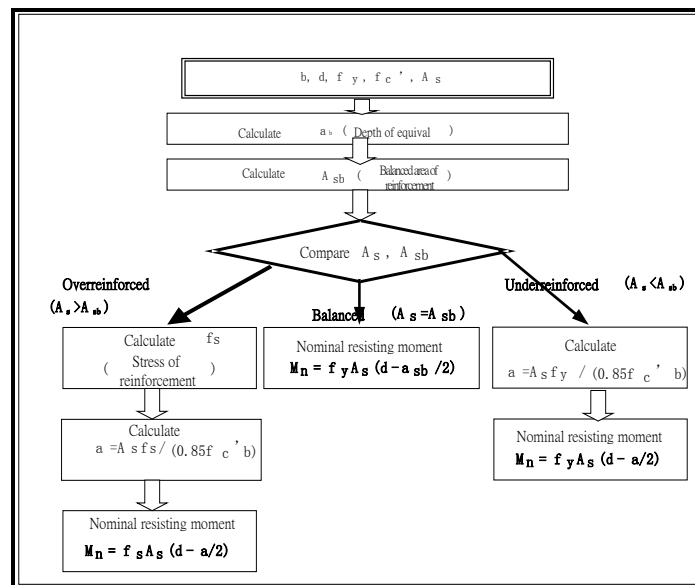


Figure 1. The calculating procedures for selecting subject.

The designed procedures are illustrated as follows:

Defining subject's concepts: The first design step is to define the subject's concepts. There are twenty-one concepts ($C_j, j = 1 \sim 21$) are derived from multiple experts for selecting subject.

Defining subject's calculation formulas: After analysis, there are 22 calculation formulas ($Q_i, i = 1 \sim 22$) for selecting subject.

Evaluation between concepts and formulas: In this step, we develop the relationship between formulas and concepts.

Construct the logic structure of solution: The basic design of Petri-Net includes four sets, are transitions (T), places (P), input relation (I) and output relation (O), then the quadruple $PN = (P, T, I, O)$ is called a Petri-Net. After over 30 years' development, the typical application domains include

industrial processes, business process modeling, hardware design, communication protocols and parallel programs etc. By utilizing the strong point of Petri-Net, we purpose a Rule-based Petri-Net to construct the logic structure of solution for test subjects. Figure 2 shows a unit of the Rule-based Petri-Net. There are four sets (parameters, calculating function, output arc and input arcs) for each unit. Parameter that links up input (output) arc is an input (output) parameter. Parameter can be a member of input, output or both parameters. The operating rules are:

- (1) The calculating function is fired, when all input parameters are known numbers.
- (2) After calculating function firing, the output parameter is calculated and is known.
- (3) A calculating function can be fired only once.

For the example in Figure 2, the total tensile force (T) is measured and is known, when the area of reinforcement (As) and the stress of reinforcement (fs) are known.

The purposed Rule-based Petri-Net is represented as Figure 3. There are four different sets in this net system. Because some parameters are both input and output parameters that makes ordering links between different calculations. This net system can represent concurrency and synchronization. Therefore, it is very adequate to construct the logic structure of solution.

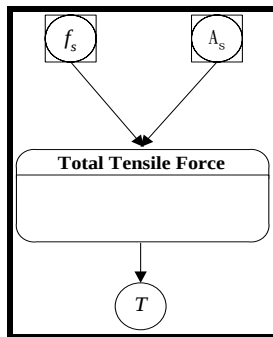


Figure 2. An independent unit.

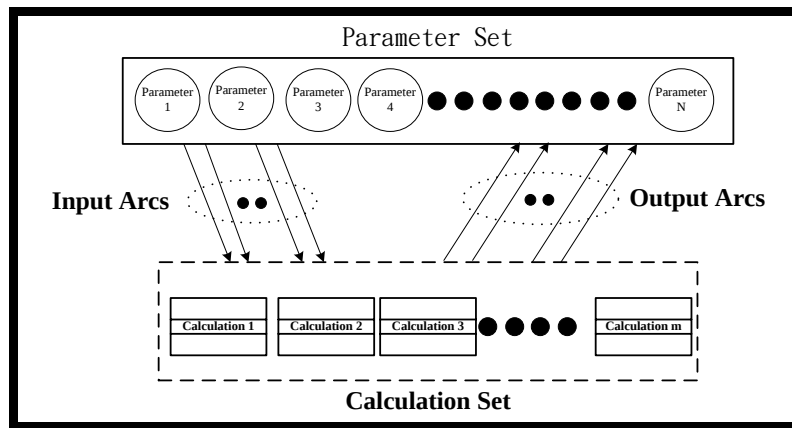


Figure 3. The model of the Rule-based Petri-Net.

3. Test items generator

In our purposed assessment system, test items can be changed automatically by following the adjustment of test concepts. The Petri-Net structure is used to develop the test items generator. An example shown in Figure 4 is used to explain the algorithm of test generator. This example is a logic structure of solution that is represented by Petri-Net. There are 4 concepts (C), 6 calculations (Q), 12 parameters (P) and 18 arcs in this Petri-Net.

- (1) If the selecting test concepts are concepts 1 and 3, system will find the relative calculations (Q_1 and Q_5) by mapping.
- (2) From the selecting calculations (Q_1 and Q_5), system will process the relationship checking to find test calculations between selecting calculations. After relationship checking, the test block (rectangular area in figure 4) is found and 5 testing calculations ($Q_1 \sim Q_5$) are confirmed.
- (3) From the diagram of test block, 5 given parameters (P_1, P_2, P_3, P_6 and P_{10}) and 1 decoded parameter (P_{11}) are verified.
- (4) Test items generator will provide the values of given parameters and ask examinee to calculate the decoded parameter.

Partial scoring function: The system uses two mechanisms to estimate the score. The first one utilizes Goldsmith's closeness index (GCI) to measure similarity between correct concept map and examinee's concept map. The second one is the correct rate of calculations (CRC). By using both GCI and CRC, the final score is calculated likes (1) as follows:

$$\text{Score} = WC \times GCI + WS \times CRC \quad (1)$$

Where

Score: Final score.

GCI: The value of Goldsmith's Closeness Index.

CRC: The value of Correct Rate of Calculations.

WC: Weight of GCI (0~1).

WS: Weight of CRC (1-WC).

Goldsmith's closeness index (GCI): Goldsmith's method is used to compute the closeness index and the computing processes. The steps involved are listed as follows:

- Determine all sub-nodes $N = N1 \cup N2$.
- For each sub-node (n_i) belonging to N
 - ◆ Locate its first-order neighbor sets.
 - ◆ Compute the intersection, $I^{(i)}$ and the union, $U^{(i)}$.
 - ◆ Calculate the closeness coefficient, $C^{(i)} = I^{(i)} / U^{(i)}$.
- Compute the closeness index, $C(H1, H2) = 1 / \sum C^{(i)}$. The value of C ($H1, H2$) represents the closeness index.

An example for GCI comparison is shown in Figure 5. The comparison between teacher ($H2$) and examinee ($H1$) is made.

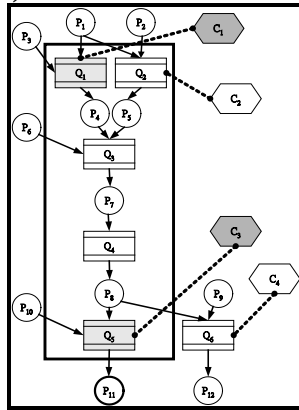


Figure 4. Example's Petri-Net.

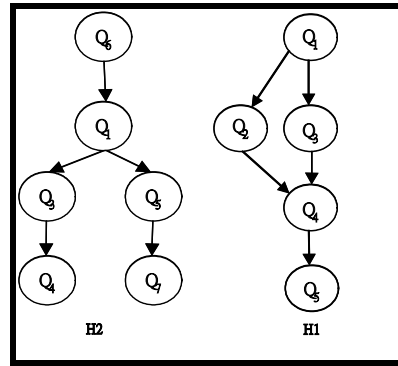


Figure 5. Example for GCI comparison.

Correct rate of calculations (CRC): The CRC is to investigate the result for each calculation. There are a series of calculations within a test item for many engineering courses. Mistakes of the parent calculations may inherit to their child calculations. Therefore, the system's judgment for each calculation is divided into six levels.

Misconception evaluation: From the result of equation 2, we can find the complete rating value for each test calculation. After referring the table of evaluation between concepts and calculations, the examinee's misconceptions can be investigated.

$$CRV^{(i)} = WC \times C^{(i)} + WS \times P_i \quad (i = 1 \sim m) \quad (2)$$

Where

$CRV^{(i)}$: The Complete Rating Value of calculation i .

$C^{(i)}$: The closeness coefficient of calculation i .

3. System Illustrations

This assessment system is developed on the Windows platform, written by Visual Basic. It uses MS Access as the database system. It has four sub-systems (modules): Test Items Generator, Concept-Mapping Reply Sub-system, Answering Evaluator and Diagnostic Evaluator, are explained as follows:

Test Items Generator (TIG): The TIG can build test items automatically by following the selecting test concepts and style. The values of the testing variables are generated randomly. Therefore, the same testing problem will be shown within different variable values for different tests. The answering evaluator will calculate the correct answers correspondingly. The diagnostic evaluator will then trace the processes of the user's operations and identify the users' misconceptions.

Concept-Mapping Reply Sub-system (CMRS): The CMRS employs an examinee's reply environment using the concept mapping technique. Examinee must draw the concept map and answer the calculation results for each calculating step for the test subject. CMRS can record all examinee's operations for evaluation.

Answering Evaluator (AE): The AE obtains the problem's correct answer.

Diagnostic Evaluator (DG): The DG diagnoses users' problem solving skills.

The operation of this assessment system is divided into four steps that are (1) select the testing subject; (2) select the test concepts and style; (3) reply and (4) view the diagnostic result.

The system's entry screen is to select the test subject shown in figure 6. After test subject is selected, the test concepts and style must be assigned shown in figure 7. Three different test styles (independent, partial combination and complete combination) can be selected.

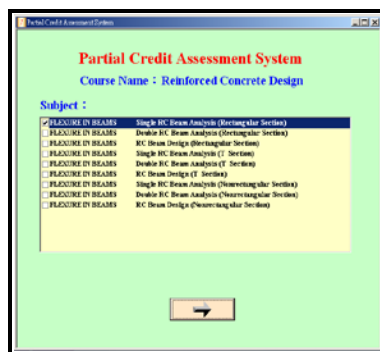


Figure 6. Select test subject.



Figure 7. Select concepts and style.

The description of test item is shown in figure 8, the values of given parameters are assigned by computer randomly. The answering evaluator is shown in figure 9. It can show the correct calculating procedures and correct value for each calculation step by step.

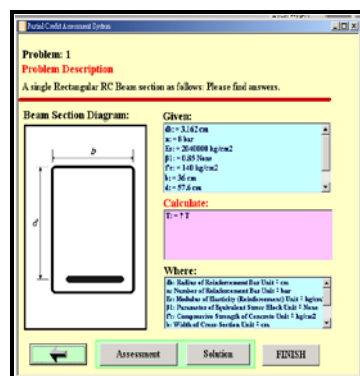


Figure 8. Problem's description.

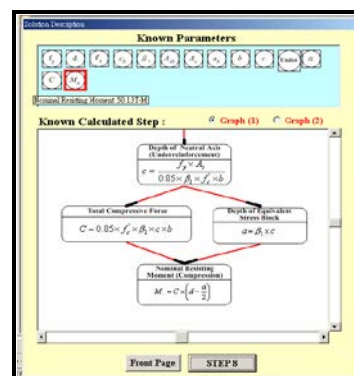


Figure 9. Answering evaluation.

Figure 10 shows the concept map reply sub-system. Examinee can reply his or her answers by using the concept mapping technique. Figure 11 shows the assessment results. It contains the problem's description, correct answering procedures and examinee's answering procedures.

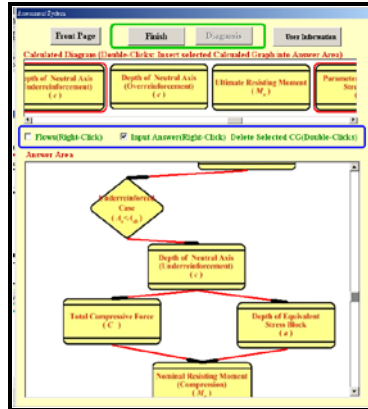


Figure 10. Concept map reply sub-system.

Figure 11. Assessment results.

3. Conclusions

This research develops a partial scoring assessment system. This system adopts the dynamic state to make out test items. The values of the testing variables are generated randomly. Therefore, the same testing problem will be shown within different variable values for different tests, to prevent students from memorizing the answers. We also purpose a Rule-based Petri-Net model for building the structure of answer logic and it can match the dynamic pattern and random parameters completely. This system adopts concept-mapping environment as examinee's reply system, can acquire enough information to investigate examinee's misconceptions and measure final score by using partial scoring strategy.

The objective courses of this system are within design procedures, logic reasoning and accounts. Many engineering courses are matching these conditions. In regard to the field of civil engineering, many courses, such as reinforced concrete design, steel design, pavement design, concrete proportioning design etc., agree on demands. This assessment system, not only can give student's grade fairly, but also can make the inference to examine examinee's misconceptions. This system can be a useful tool to assist teacher's teaching and student's practice.

The standalone version was finished. Now, we are developing the network version. In the future, we will actually practice and test this system in class, to improve system's functions with solid experiences and extend this system to universities or colleges, to save the teachers' time for grading paper examinations.

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