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FORMATIVE ASSESSMENT IN ENGINEERING USING "TRIADS" SOFTWARE

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Formative Assessment in Engineering Using "TRIADS" Software

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Abstract

If assessment is influential in driving student learning, then interesting and challenging assessments should enhance the learning process. This paper describes how we have tried to implement this philosophy in our introduction of computer-based assessment (CBA) using TRIADS (Tripartite Interactive Assessment Delivery System) in Chemical and Civil Engineering at the University of Birmingham. Our aims in using CBA in Engineering are to encourage students to be independent learners, to foster a deep approach to learning, whilst maintaining high quality teaching with reducing staff-student ratios. To achieve these aims it was decided that we needed software that met two main needs: first, to contain a wide range of question styles that could support higher learning outcomes consistent with Bloom's taxonomy of learning objectives and secondly could be used for formative assessment in which the feedback could be configured to direct student learning. TRIADS was selected as it meets these criteria and allows the tutor a high degree of flexibility in configuring the questions. To demonstrate the ability of TRIADS to meet these criteria this paper describes our development and implementation of formative assessments in Chemical and Civil Engineering. In Chemical Engineering a tutorial based on CBA was held with a first-year class of 38 students. The results of the assessment were recorded in order to evaluate question design; initial results and feedback from the students implied that a high level of independent learning took place. In Civil Engineering the CBA was for taught MSc students. The focus was on designing varied and challenging questions to test higher level learning outcomes and to give answer-specific feedback to direct further student learning.

Introduction

In many engineering taught programmes there is mounting pressure to increase student numbers whilst at the same time reduce student-staff contact time. To cope in these circumstances and simultaneously maintain the quality of the taught programme, computer-based learning and teaching methods are being used in engineering subjects at the University of Birmingham to support lectures and tutorials delivered using traditional methods.

If assessment is influential in driving student learning, then interesting and challenging assessments should enhance the learning process. This paper describes how we have tried to implement this philosophy in our introduction of computer-based assessment (CBA) using TRIADS (Tripartite Interactive Assessment Delivery System) in Chemical and Civil Engineering at the University of Birmingham. Our aims in using CBA in engineering are to encourage students to be independent learners, to foster a deep approach to learning, whilst maintaining high quality teaching with reducing staff-student ratios. To achieve these aims it was decided that we needed software that met two main needs: first, a wide range of question styles that could support higher learning outcomes consistent with Bloom's taxonomy of learning objectives (Bloom, 1956) and secondly could be used for formative assessment in which the feedback could be configured to direct student learning. TRIADS was selected as it meets these criteria and allows the tutor a high degree of flexibility in configuring the questions (MacKenzie, 1999).

To demonstrate the ability of TRIADS to meet these criteria this paper describes our development and implementation of formative assessments in Chemical and Civil Engineering. In Chemical Engineering a tutorial based on CBA was held with a first-year class of 38 students. The results of the assessment were recorded in order to evaluate question design; initial results and feedback from the students implied that a high level of independent learning took place. In Civil Engineering the CBA was for taught MSc students. The focus was on designing varied and challenging questions to test higher level learning outcomes and to give answer-specific feedback to direct further student learning.

Finally the value of the exercise is discussed based on (i) our experience of using TRIADS with student groups, (ii) student performance on the questions and (iii) student feedback.

Background

Encouraging a Deep Approach to Learning

Engineering is a subject in which students apply their theoretical knowledge to solve problems and carry out design work. Therefore academic engineering departments are faced with the challenge of motivating students to develop their understanding, judgement and problem-solving techniques.

Although most engineering taught programmes already incorporate design and laboratory project work, much of the core material is still delivered by didactic lectures supported by tutorials. Ideally the tutorial aims to offer a 'learning by doing' experience to the student (Gibbs, 1992). To facilitate this, tutorial sessions should contain high staff-student ratios enabling individual guidance to be provided. However, in practice in many academic departments large class sizes and low staff-student ratios exist. These can lead to problems in tutorial and seminar work as described by Gibbs and Jenkins (1992). The authors believe that by introducing CBA to their subject areas such problems may be addressed and at the same time students will be encouraged to adopt a deep approach to learning.

Benefits and Costs of CBA

In the two engineering courses described here CBA has been introduced to encourage student-centred learning, to provide students with detailed feedback on their progress and to direct them to learning resources. If this can be done effectively, student-staff contact time may be reduced without reducing the quality of the delivered product.

Gibbs *et al*. (1993) point out that the development of computer-based assessments involves a considerable investment of time on the part of the academic. Later in this paper an estimate of the time spent in setting up the questions is made. Also, in order for students to have access to the assessments intensive use of computer facilities may be required.

Bloom's Taxonomy and CBA

In applying CBA in the two engineering courses, it was recognised that the depth of student learning should be tested and encouraged at a number of levels. These include testing students' basic knowledge of the course content, testing their conceptual understanding and testing problem-solving skills. These different levels of learning have been classified by Anderson and Krathwohl (2000), extending Bloom's taxonomy of learning objectives (Bloom, 1956), as respectively factual, conceptual, and procedural. The additional level of learning, the metacognitive knowledge dimension, also set out by Anderson and Krathwohl, in which students become aware of how they come to know and learn, is not addressed.

In order to match these knowledge dimensions with the need to write learning objectives, Anderson and Krathwohl (2000) proposed six levels at which students may be tested on each knowledge area (Table 1). These levels have been used as a basis for the design of CBA questions in Engineering. One of the main reasons for using the TRIADS software is because it offers a wide range of different question types (MacKenzie, 1999) which may be used to assess many of the levels of learning proposed by Anderson and Krathwohl (2000).

<table>
<tr><th>Knowledge Dimension</th><th>Remember</th><th>Understand</th><th>Apply</th><th>Analyse</th><th>Evaluate</th><th>Create</th></tr>
<tr><td>Factual Knowledge</td><td colspan="2" rowspan="4">Foundation thinking</td><td colspan="4" rowspan="4">Higher level learning outcomes</td></tr>
<tr><td>Conceptual knowledge</td></tr>
<tr><td>Procedural knowledge</td></tr>
<tr><td>Metacognitive knowledge</td></tr>
</table>

Table 1. Revised Bloom's taxonomy by Anderson and Krathwohl (2000)

Chemical Engineering

Methodology

Reaction Engineering is taught to each year group of students in Chemical Engineering at Birmingham. The first year Reaction Engineering course introduces the principles of chemical reactor design and reaction kinetics, drawing on students' knowledge of other subjects such as mathematics, chemistry and thermodynamics. Although there is a basic need for students to recall factual information and definitions, it is essential for them to build on concepts learnt in other courses and apply their knowledge to the solution of reactor design problems. Therefore the introduction of CBA needed to test both foundation thinking and higher level learning outcomes.

In Chemical Engineering, 28 questions were developed, which were grouped into 10 topic areas, each containing an average of 3 parts. Each part of the question was designed to test a progressively higher learning outcome. For example, a typical 3-part question set involves:

- A *multiple true/false* question, testing students' ability to remember and understand factual information.
- A *label diagram* question in which they have to apply procedural knowledge to perform a mathematical operation.
- A *text entry* question set up for numerical entry, in which they have to analyse a problem and calculate an answer.

Since the latter part of each group of questions followed on or required information from an earlier question, all questions were arranged in a sequence, with the order following that of the course syllabus. Figure 1 illustrates a typical question, showing a screen capture of a *label diagram* question in which students are asked to integrate a rate equation.

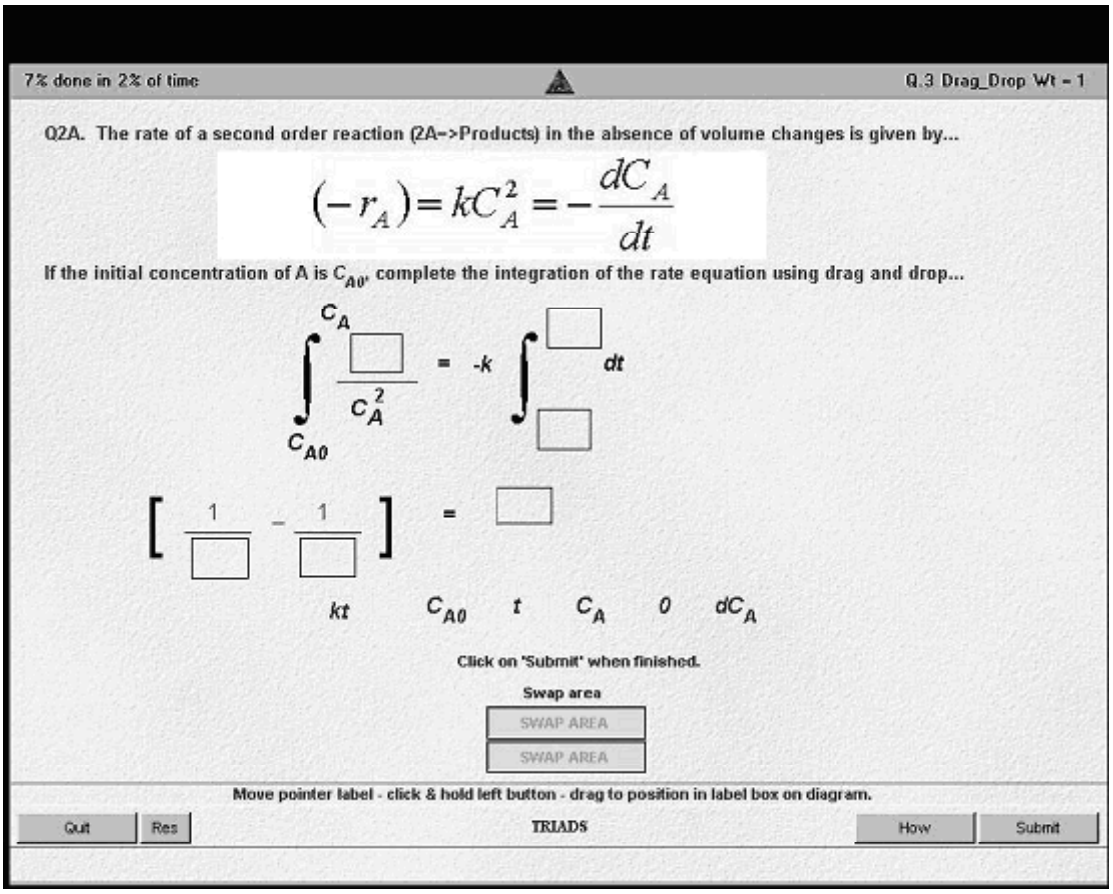


Figure 1 Label diagram question configured for integration of a rate equation

Results and Discussion

Student Feedback on CBA

Students were given a questionnaire on the TRIADS tutorial, which supplemented the standard course feedback form. Table 2 shows the questions and student responses, graded from 1 - 5, with 1 representing 'strongly disagree' and 5 representing 'strongly agree'. Only 19 of the 38 students who completed the assessment returned the questionnaire, and some omitted certain answers. The results presented in Table 2 indicate that students generally agreed that it was easy to understand the questions in TRIADS, the instructions on how to answer the questions were clear and that the TRIADS tutorial helped them to understand the lecture notes. Most students however thought that more feedback was needed and this issue in particular has been identified as an area in which the Chemical Engineering tutorial could be improved. Finally, whilst 10 students thought the TRIADS tutorial helped them to assess their progress on the course, 3 were indifferent and 3 disagreed that TRIADS was helpful in this respect. Overall, the student feedback was constructive, showing that the TRIADS assessment was a valuable exercise in encouraging independent student learning and identifying a number of areas in which the assessment could be modified or improved.

Question response (1 = strongly disagree, 5 = strongly agree)	1	2	3	4	5
Questions	Number of student responses				
1. It was easy to understand the questions in TRIADS.	-	-	3	5	10
2. The instructions on how to answer the questions were clear.	-	-	3	6	9
3. The TRIADS tutorial helped me to understand the lecture notes.	-	-	4	7	7
4. The TRIADS tutorial was more helpful than the other tutorials.	1	2	5	4	6
5. More feedback is needed if you get the questions wrong.	-	-	1	4	14
6. There were too many questions.	-	1	6	6	4
7. The marks helped me to assess how I am doing on the course.	1	2	3	6	4
8. I would like to be able to choose which questions to do rather than answering in sequence.	4	2	4	2	5

Table 2 Results of student feedback questionnaire on TRIADS tutorial in Chemical Engineering

Quantitative Results

In Chemical Engineering the results of the one-hour introductory sessions were recorded automatically by the TRIADS software for the purposes of evaluating the design of the questions and assessment, rather than to assign a mark to a particular student. Figure 2 displays the scores achieved by students based on the number of questions attempted. From this figure it may be seen that all but 2 students scored over 70 % from the questions answered. This indicates that they were working through the assessment systematically, rather than guessing the answers and provides evidence of the high level of independent learning taking place. Figure 3 shows the number of questions attempted. The peak at 16 questions is thought to correspond to students who spent one hour on the test, whilst the peak at 28 represents students who stayed for longer than an hour in order to complete the whole assessment.

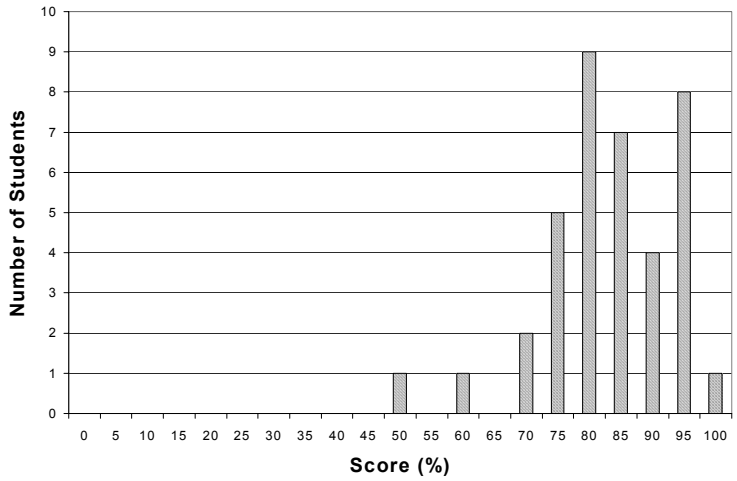


Figure 2 Distribution of student scores from questions attempted

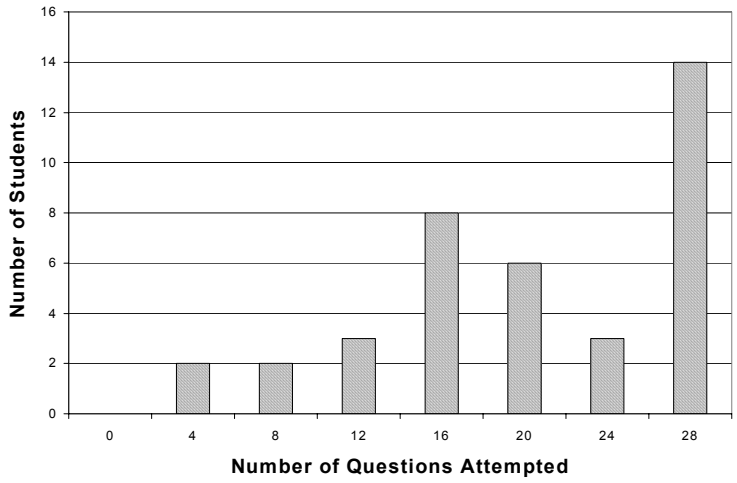


Figure 3 Number of questions attempted

Civil Engineering

For the reasons described earlier CBA are being introduced to the Highway Management and Engineering MSc taught programme. As part of a pilot study it has been initiated on one course of the taught programme, that of Highway Drainage. It was decided to develop a formative assessment, based on existing tutorials and covering the entire Highway Drainage syllabus, which could be used by students as an independent learning resource. To this end the assessment was made available on CD ROM and from a web server, enabling students to use the resource wherever and whenever they wished. The assessment consisting of twenty-two questions was developed using a variety of different question types to test as many as possible of the various levels of student learning and understanding as characterised by Anderson and Krathwohl's Revised Bloom's taxonomy (2000). Table 3 below lists the question types used and the levels of learning which they seek to test (note

that the metacognitive class of knowledge has been excluded as it is not subject specific). It may be seen from Table 3 that the majority of question types were used to test higher level learning outcomes, i.e. the students' ability to apply analyse and evaluate. As yet we have not designed a question to test a student's creative ability as defined by Anderson and Krathwohl (2000).

Philosophy Used in Design of Feedback

The 22 questions were developed to incorporate a new module which can be configured by the tutor to give various types of feedback to the students to direct further their learning. The module was designed to allow feedback to be given which is specific either to the answer given or the score achieved (depending on the question type).

In the current configuration, after answering a question, each student is provided with a score and an indication of which parts of the question they got right or wrong.

In the case of correctly answered questions, where appropriate (such as in the case of a calculation question), the student is provided with a fully worked solution to the problem. This provides students with the opportunity to check their working. Additionally, a list of texts which the student may read in order to gain additional background knowledge of the subject is provided.

For a partially correct answer the student is provided only with the correct answer if their score for the question is above a certain threshold. This threshold score may be set by the tutor uniquely for each question and depends on the difficulty of the question. In the pilot study the threshold scores of questions assessing the higher levels of learning were set at a higher score than those testing the lower levels as such questions are considered to be more difficult to answer correctly (King and Duke-Williams, 2001). No fully worked solution was provided for partially correct answers, but references are provided to other resources, such as lecture notes or texts. These should be read by the student to gain further insight and understanding of the problems posed by the question.

We believe that this approach will encourage our students, who in this case are postgraduates, to become more independent learners. As yet we have not had sufficient feedback either from them or their scores to know whether we are right in our belief.

Example

An example of a multiple choice type question is given in Figure 4 below. This question was designed to evaluate the students' ability to remember and understand both general and subject-specific concepts and principles. Furthermore, to answer the question correctly, the student has to understand and apply these concepts. Finally, the student has to use various analytical skills to evaluate the correct answer. Accordingly, the question is designed to test conceptual and procedural knowledge.

With reference to Figure 4, students who answer a question correctly are able to access the solution, shown in Figure 5, to the problem by clicking on the

button labelled “Solution” (this button is not displayed on the screen if the student fails to answer the question correctly). A list of additional texts which the student may wish to read can be obtained by clicking on the button labelled “Further study”.

Knowledge Dimension	Remember	Understand	Apply	Analyse	Evaluate
Factual	LD	FBT			
Conceptual		PH	LD, MCMA	AR, AR, LD	
Procedural		MQMA, MR	LD, FBT, FBT	PH, AR, FBT, AR	MQMR, MR, LD, MQMR, MC

Key: MPH: Multiple polygonal hotspot; LD: Label diagram; FBT: Fill in blanks in text, AR: Assertion-reason; MC: Multiple choice; MQMA: Multiple question, multiple answer; MR: Multiple response; S: Sequencing.

Table 3 Highway drainage question types according to the level of learning tested

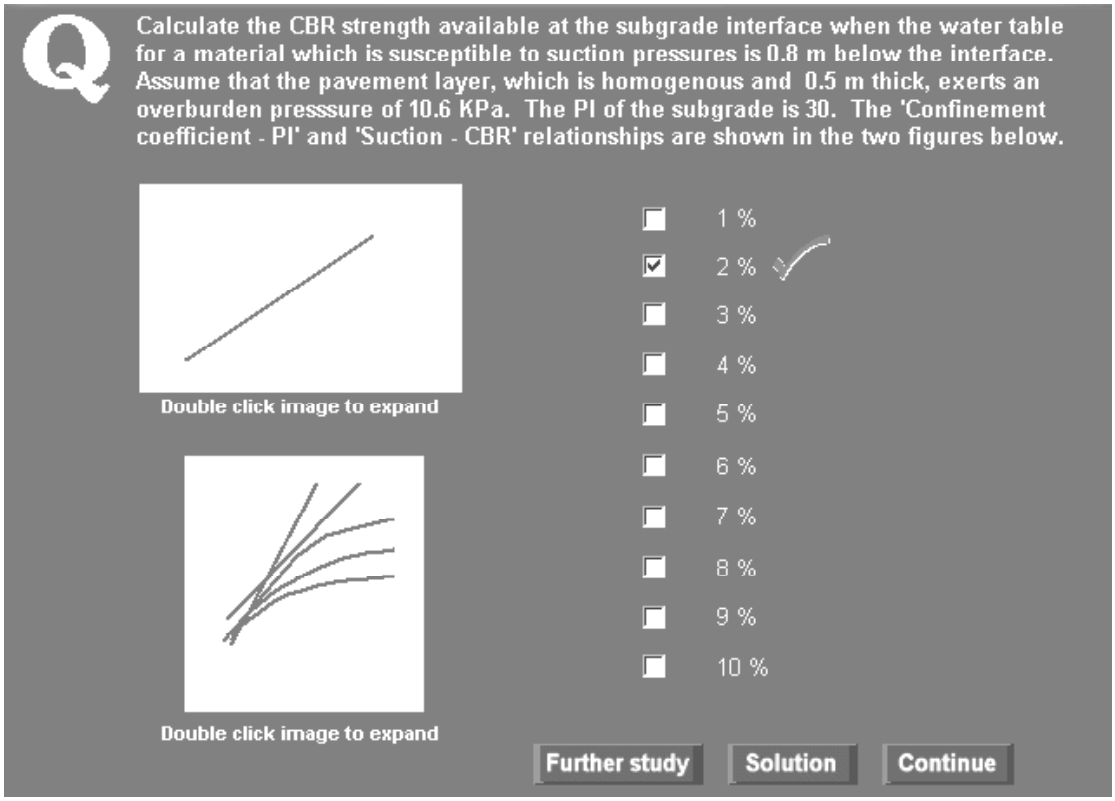


Figure 4 Example of a multiple choice question used in Highway Drainage

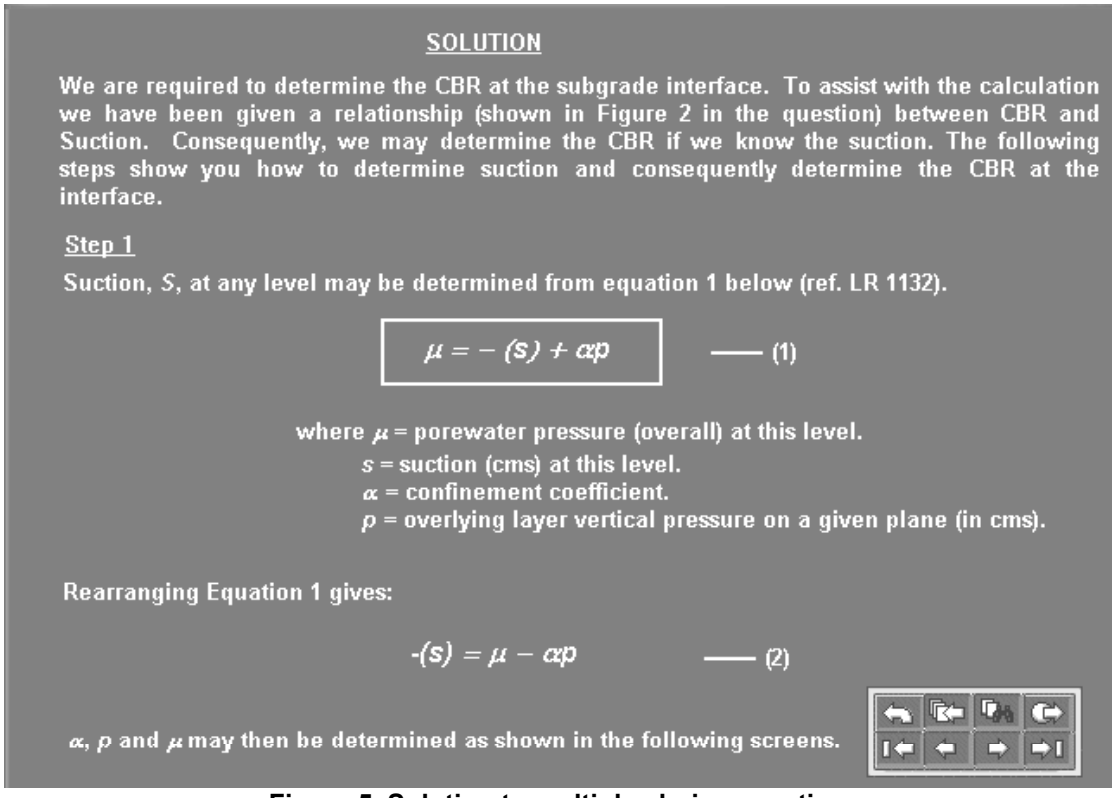


Figure 5 Solution to multiple choice question

Benefits and Costs of CBA

The major costs of setting up the two assessments described here have been staff time and the use of resources. As far as staff time is concerned most of the time was spent on question design. Whilst in both cases a mixture of existing paper based questions and newly developed questions were used, the majority of the time was spent in programming the questions in the TRIADS environment. In the case of the Chemical Engineering course, questions took on average 2 hours to prepare, whilst in Civil Engineering the time spent per question was 2½ hours. The difference in the time spent on question preparation between the two subjects is due to the fact that extensive feedback has been developed for the Highway Drainage course in Civil Engineering. A small amount of additional time was spent by other members of staff critically reviewing the questions and feedback provided.

As mentioned previously, it is hoped that the benefits of introducing CBA will be to reduce student staff contact time whilst at the same time fostering a deep approach to independent learning. At this stage of the development of the exercises it is difficult to quantify these benefits. Whilst, the time taken to prepare a question may appear to be a considerable it is proposed to reuse the questions in subsequent years. Consequently, it is considered that the benefits, in terms of the potential reduction in student staff contact time and the improvements in student learning will, in the medium and long term, outweigh the costs in staff time taken to develop and set up the assessments.

Conclusions

The TRIADS software was used to test a wide range of learning outcomes in Chemical and Civil Engineering, consistent with Bloom's taxonomy (Bloom, 1956; Anderson and Krathwohl, 2000). The TRIADS software is considered to be a useful tool in encouraging independent and deep learning. It can therefore be used to help maintain quality in taught programmes where staff-student ratios are an issue. In engineering positive student feedback and high scores on the questions attempted provided evidence that the introduction of CBA was generally successful. In future years, development work in both subjects will focus on further developing the on-screen feedback to each question. Future plans in the School of Engineering at Birmingham to merge the Chemical and Civil Engineering PC clusters will lead to further integration in methods of developing and running CBA.

Acknowledgements

We are indebted to Professor Don MacKenzie and his team at the Centre for Interactive Assessment Development at the University of Derby for the provision of TRIADS software without charge and for their advice and assistance. We are also particularly grateful to Dr. Richard Freer-Hewish and Mrs. Barbara Hallam who have been heavily involved in the developing the Highway Management and Engineering Course. Thanks are also due to Mr. Bob Hunter and Miss Jennifer Harvey of the Learning Development Unit at the University of Birmingham for their help with various aspects of the project. Finally, we would also like to thank Mr. Tony Roberts, of Chemical Engineering at Birmingham for providing invaluable technical assistance.

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