Creating appropriate online assessment for quantitative engineering courses

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***Abstract**: Quantitative Engineering courses typically require students to solve complex mathematical problems with many parts all based on the same data. Students should be able to identify as well as apply the correct mathematics for each step. When assessing student answers it is common to give part marks for correct calculations, even if the answer is incorrect. If the first part of the answer is wrong, but subsequent parts are correct, marks should be awarded for the correct parts. This paper describes the use of two online quiz systems in several engineering courses and discusses how effectively they accommodate the requirements above. End of course survey results show that students prefer online assessment to traditional hard copy assignments. Comparison of online assessment results with similar questions assessed traditionally show higher results, indicating that online assessments encourage students to put more effort into obtaining the correct answer.*

Introduction

This paper discusses the use of computer assisted assessment (CAA) in several quantitative Engineering courses. In these courses CAA was used to provide assessment in the form of assignments that students were able to complete in their own time. These assignments functioned as both formative assessment and summative assessment. They were formative because students received feedback on their results and so were guided in their studying for the final exam. They were also summative to ensure that students actually completed the assessment and put a reasonable effort into them.

Prior to the use of CAA these assignments were carried out in the traditional paper based manner where the questions were printed on paper and distributed to the students. The students had to record their answers on more paper to be submitted in class. The assignments were manually marked and annotated with feedback. They were then redistributed to the students as an aid for learning.

The research into this type of online assessment using numerical questions that students can complete in their own time appears limited. Conole and Warburton (2005) trace the history of CAA, but only discus multiple choice questions. Gipps (2005) claims the most common format is multiple choice and other forms of selection from a list. Kendle and Nothcote (2000) equate quantitative assessment in online assessment with closed, as opposed to open ended, questions and include such things as multiple choice. Phillips and Lowe (2003) give a long list of online assessment analogous to traditional assessment, but do not include any numerical assessment types at all.

Several advantages were expected to result from moving to the use of CAA.

- Timely feedback. Using CAA enables the possibility of automatic marking by computer. This means that the results and feedback can be returned to students much faster than in the traditional paper based method where the students had to wait for both time for the marker or markers to mark the assignment and also in many cases for the next opportunity for the work to be returned. In the extreme case CAA can give the feedback virtually instantaneously.
- Individualised questions. Given that the students are able to do the assignments in their own time there is a lot of scope available for students to cheat in their assignments. Rowe (2004) highlights the danger of cheating in online assessment and claims that cheating is much more common than academics are aware of. This defeats both the formative and summative aims of

the assignments when students copy from each other. Given that the assignments are quantitative in nature it is difficult to detect when the students copy, unless they get the wrong answer. However, CAA gives the option of assigning different questions, and different numbers for the same questions, to different students. This means that students cannot simply copy from each other. Instead if students decide to cheat they must rework out the answers using the new numbers. It is expected that this exercise would be more collaborative than simple copying and thus students are likely to learn something even when cheating. Thus at least the formative goal will still be achieved.

- Students can access and submit the assignment anywhere they have an internet connection.
- Guaranteed records of submission and prevention of assignment loss. Using the traditional paper based submission of assignments allows the twin problems that the marker may mislay an assignment, or that a student may have failed to submit an assignment and then later claim that they did. Use of a CAA system ensures that neither of these situations occurs.
- Environmentally friendly. Much less paper is used in a CAA system.

Selection of CAA System to be used

There is a large variety of CAA systems on the market. Some of the major stand alone products include QuestionMark Perception, Quiz Factory 2, CyberExam, Test Pilot, Hot Potatoes and WebMCQ. In addition many elearning course management systems include a CAA subsystem. Examples include Moodle, Blackboard and WebCT.

In selecting the CAA system to be the used the main criteria was availability at the university. This university was using WebCT Vista version 3 as its centrally supported platform for eLearning. WebCT Vista had an inbuilt quiz system with a variety of question types. Of particular relevance were the “Calculated” question type and the “Fill in the Blank” question type.

The calculated question type allows the use of “variables” in the question. These variables are used in place of numbers in the question. A formula is provided for the correct answer based on these variables. The system then generates up to 100 sets of random numbers to be used for these variables, with each of the variables fitting inside limits set by the question author. These random numbers can then be edited by the question author if necessary. The question author can also set the tolerance of the numerical answer that will be accepted. Each student is then given one of these sets of different numbers when they sit the quiz. The biggest drawback to this question type is that each question can only contain a single numerical response field.

The “Fill in the Blank” question type allows the question author to leave spaces in the question that the student has to fill in. This enables a single question to contain multiple response fields. For example, a structural engineering question could provide the dimensions and physical properties of a truss together with its loads and ask for the displacements at each individual joint. The disadvantages of this question is that it is only a text matching question so it is not possible to set tolerances on the answers and there are no random variables, so students all get the same numbers in their questions. The appearance of different numbers can be obtained in this question by writing several versions of the same question, each with different numbers inserted. These different versions can be offered in a “question set” where each student is given only one version from the set.

Another CAA system available was Question Mark Perception. This system had a much wider variety of question types. However, regarding numerical type questions it had no advantage over WebCT Vista. Therefore initially the WebCT Vista system was used, as the overall system was already in use by many of the courses at the university and therefore more likely to be familiar to the students.

Later a licence was obtained by the university for Maple TA. This system is specifically designed for asking mathematical questions, including symbolic algebra questions. One of the key advantages that it has for the work described in this paper is that it has both the ability to use random values in any question and also a question type that allows multiple response fields in a single question. Since this system has become available several new assignments have been created using it, and several of the existing assignments created in WebCT Vista have been converted.

Assignments implemented in WebCT Vista

Risk Management Course

Traditionally a paper based assignment was given to the students covering some of the quantitative material in this course. This included some basic probability and statistical inference theory to ensure that all of the students had the same level of background understanding and some material covering fault, event and decision trees. Other assignments covered the non-quantitative aspects of applying the theory to case studies. The questions on probability tended to require the students to recognise which probability distribution applied in a particular case and determine a particular probability using it. The questions on fault, event and decision trees required the students to draw the tree relevant to a particular situation and then calculate an answer based on it.

In moving to CAA this assignment was split into two separate assignments, the first covering the probability and the second covering the fault, event and decision trees.

Converting the probability questions to the online format was fairly straightforward. The Calculated question type was used with the answer being the probability that had to be determined.

Converting the fault, event and decision tree questions to the online format sacrificed the ability to assess the students' drawings of the trees. Most of the questions asked for the results of the calculations performed on the trees. Generally the result of the calculation would be a single number, although several steps might be required to arrive at this. With regard to drawing a fault tree a pseudo-multiple choice question was devised involving three basic events where students were shown all eight possible fault trees that could be drawn using those events and had to select the correct one. However, the correct fault tree depended on the specific values of several numbers in the question. However, changing the numbers provided in the question changed the answer between five of the options. Other questions were then provided regarding the calculations.

One of the problems with WebCT Vista calculated question types is that it does not contain if...then...else operators. This functionality is needed for calculating the results of decision trees. However, it does provide the exclamation mark as a "not" operator. The not operator converts a zero into a one and anything else into a zero. Therefore "if (A < B) then C else D" could be written as:

$$!!(\max(A, B) = B) * C + !(\max(A, B) = B) * D$$

Rickets and Wilks (2005) found that students tend to perform better in online assessment than they would for the same questions asked in a traditional manner. This result was also found in this course where the median mark for the sum of the two CAA assignments was approximately 10% above the marks for equivalent assignments in previous years. Thus the online format of the assignment encouraged the students to work harder at making sure that they got the right answer. This was particularly obvious in the second quiz, where a high proportion of the students got all the questions correct, or only one question wrong, even though they may have done poorly on the first assignment, despite the questions being more difficult than in the first assignment.

This result of students performing better on the second and subsequent assignments has been observed in each of the courses where more than one of this type of online assignment has been used. This may be caused by two possible reasons. Firstly the result from the first assignment may be depressed because the students are unfamiliar with the CAA environment. This is unlikely because the students are simply entering the wrong answers, they don't use the CAA environment to calculate the answers, and this is all done offline. More likely the reason is that when the students receive their feedback on their wrong answers it encourages them to work harder on the subsequent assignments.

Project Scheduling Course

Traditionally a series of paper based assignments was issued to the students covering the drawing of project networks, calculating activity start and finish times, compressing project duration, and allocation of resources. This is more difficult than the previous course because each "question" really requires multiple answers, plus there is the problem of assessing ability to draw networks.

The problem of drawing project networks was tackled by creating questions that provided the activity data labelled using letters, and the correct network diagram labelled using numbers. Students then had to match the letters to the numbers. In other questions the students had to identify which activities had been put in the wrong places in the network diagrams. The final type of question provided several unlabelled network diagrams and the students had to select the one that matched the activity data provided. For each of these questions multiple versions were provided to minimise cheating between students. Generally the same picture or diagram would be provided for every version, but the activity data or labels would change. Thus students who blindly copied answers from their friends were highly likely to have the wrong answer (students were warned about this).

Questions involving calculation of activity times were implemented using the calculated question type. This has the drawback of having only one answer field per question. However, the question type does have an optional answer field for the student to provide units (metres, kilograms, etc.). However, this functionality provided a backdoor way of obtaining multiple answer fields. For example in one question where students were required to calculate float values the students were instructed to enter the total float into the "answer" field and the free float into the "units" field. Since this used the calculated question type different students had different total float values. To obtain different free float values for different students several versions of the question were written each using different "units". The sets of random numbers were then hand edited to ensure that the free float did indeed equal the "units" for that question. A separate spreadsheet was used to ensure that this was the case.

The project duration compression assignment required much more calculation occurring over several steps. This assignment was implemented using the "fill in the blanks" question type. This type of question does not give students different numbers so it was necessary to write several versions of this question. Each version had the same basic network but the numbers were different. Additionally numbers were selected so that the first derivatives of all the versions were the same. This enabled the asking of a separate calculated question next based on the data of the main question.

One finding of the use of CAA in this course is that there is a big danger of the assignments becoming brittle. As mentioned above students (after the first assignment) tend to be very careful and so a lot of students will get higher marks. However, when so much work is required for each answer and the system cannot award part marks for working, or if like the last assignment mentioned above, the students stop getting awarded marks once they start to go off track then it is very easy for students to get a poor mark compared to their class mates.

Rectifying this brittleness requires that more answers be required. This dilutes the percentage of marks lost for a single simple mistake. Additionally either all of the answers need to be independent of all the others, or the system needs to be able to use the students incorrect answers when calculating the correct answers for answers that depend on them so that if they can be awarded part marks.

Discussions were entered into with the University's central elearning support team about developing a system using Adobe Flash with some of these features. The University then decided to obtain a licence for the Maple TA system, which has features which can partially address these problems.

Assignments implemented in Maple TA

Asset and Materials Management Course

This course was a new course. Four online assignments were written for this course. One of the aims in writing these assignments was that the brittleness mentioned previously was avoided by having multiple independent answers collected for each question so that the effect of single errors by the students would be minimal.

One of the advantages of Maple TA that was exploited in these assignments is that Maple TA enables the use of algorithmic variables. These variables are like variables in computer programs in that each variable can be given a name, and variables can be defined in terms of each other. This means that answers made of complicated expressions could be broken down into simpler sub-expressions. This made it easier to both write and debug the answers. In one question a golden section search (Kiefer, 1953) was implemented in 96 lines of code to find the maximum of a function. (The students were still free to use simpler methods, e.g. graphical methods, to find this maximum.) These algorithmic variables can be placed in the question text and answer fields to be substituted by (random) values calculated when the student starts the assignment.

A second advantage is the “question designer” (previously known as “inline”) question type. This question allows the insertion of multiple answer fields, all of which have access to the same algorithmic variables. This enabled each question to ask for more than one answer so that each answer given by the student was worth less marks, thus diluting the cost of accidental errors.

In this course many of the problems that the students had to grapple with were decisions, such as which piece of equipment had the lowest lifetime cost. Therefore many of the questions gave three different options and asked the students to input the cost or benefit of each and then input which was the most appropriate. This meant that it was much easier for students to get part marks as most parts of the question were independent. The final decision was usually only allocated 10% of the marks.

Woit and Mason (2003) found that typically the first online assessment in a course would have lower marks then subsequent assessments. This was found in this course. The level of difficulty of each assignment was fairly similar but the average student results in chronological order were 67%, 87%, 83% and 86% showing a dramatic jump between the first two assignments.

Students were surveyed at the end of this course about their opinions on the online assignments. When asked if they preferred online or paper based assignments 34 out of 45 students said they preferred online with 21 of these 34 saying it was “much better”. The remaining 11 students said they were “about the same”. None of the students preferred the assignments to be in paper based form.

Students were also asked if they preferred the Maple TA to the WebCT Vista. Of the 29 students who had experience of both 18 preferred Maple TA, 6 were indifferent and 5 preferred WebCT Vista.

Construction Technology Course

The traditional assignment in this course involved the students optimising an earthmoving system. This assignment required the students to determine relevant soil properties, production rates for a variety of construction machines (excavators, trucks, dozers, compactors), the optimum number of machines to use and the resulting cost. Most answers depend on the answers to previous questions.

In a paper based format the student would be given all of the data and be expected to lay their solutions out clearly. The marker would then go through and check that all of the intermediate calculations as well as the final result were correct. If the student made a mistake then the marker would check that the method for the remainder of the question was correct and award partial marks.

Maple TA has a feature called question chaining. This enables a question later in the assignment to have access to the student’s answers from previous questions (Heck, 2004). Unfortunately this only works with the “Maple graded” question type. In this question type both the correct answer and the mark awarded can be calculated by programs written in the Maple language. This goes beyond the simple algorithmic variables, being a Turing complete language with loops, arrays and other high level program control structures. However, it only allows one answer field. Also the question does not have access to the earlier question’s algorithmic variables.

In the online implementation the assignment was broken into 10 questions. The answers for some of the questions depended on the answers to previous questions. For example, the time to load the soil in a truck depended upon the capacity of the truck and the production rate of the loader. However, the values used for these parameters were those that the students had given, not necessarily the correct answer. Thus errors made earlier did not prevent students from getting marks for later questions. Regrettably even though the answers from the previous questions could be accessed the algorithmic variables could not. This meant that questions could not be written where the answer depended both upon data given in an earlier question and on the earlier question’s answer. This prevents multiple answer fields depending on the same new data when combined with previous answers.

The final two questions used a backdoor method to overcome this. The second last question provided fields for the students to enter the optimum number of excavators, trucks, dozers and compactors. The algorithmic variables needed to do this were given in the last question. This question did not have any marks “officially” allocated to it. Instead they were allocated as part of the last question’s marks.

The field in the last question asked for the overall cost of the operation. However, when grading the answer this question used the Maple language to test every reasonable combination of numbers of machines to determine the first and second most optimal combinations of machine numbers. It then awarded the student some marks if they had provided the correct optimum in the previous question. Half marks were given if the student had given the second best combination. The remaining marks were awarded if the student gave the correct cost for the job based on the numbers of machines the student had provided, whether or not they were optimal, or even plausible.

This assignment satisfies some of the major expectations for the marking of quantitative engineering assignments. The question is a much more realistic question representing real engineering that looks at a holistic problem and engages the student in calculating a solution from beginning to end. By asking for answers to intermediate steps it awards partial marks when part of the students work is correct. Finally, the students can still get marks for using the correct method on steps subsequent to a mistake.

Conclusion

This paper described the use of two online assessment systems Web CT and Maple TA for numerical assignments. It highlighted the need in this type of assignment to give different numbers to different students, and to give students partial marks when they get part of the question right. It showed that CAA assignments could be written using Maple TA such that students can still get marks for using the correct method on steps subsequent to a mistake. However, Maple TA still lacks the ability to access the algorithmic variables from earlier questions, even when it gives access to the answers to those questions. Whilst a work around is shown here, the layout of the assignment is not as clean as desired.

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