Enhancing learning and measuring learning outcomes in mathematics using online assessment

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Introduction

Rationale

In its narrowest form, 'assessment' seeks to measure the degree to which learning objectives have been met. In a broader context, it seeks to measure the achievement of graduate attributes. As such, assessment tasks should include life-like, authentic or situated activities (Cumming and Maxwell 1999). For many disciplines, including mathematics, computer technology can be seen as part of such a context. However, Englebrecht and Harding (2004) find that 'many teachers of mathematics still shy away from granting technology the same significant role in the assessment process.'(p.218). This paper proposes that online assessment offers an authentic environment under which to assess computer laboratory skills in mathematics, and further, that careful attention to the design of online assessment tasks can enhance student learning.

Background – the subjects

These propositions will be addressed in the context of three subjects, two first year mathematics subjects Operations Research Modelling (ORM) and Introductory Mathematical Methods (IMM), and a second year subject, Optimisation 1. ORM provides an introduction to the models, methods, and tools of Operations Research. Problem solving features strongly in the subject, with particular emphasis on simplified real-life problems and computational skills. The subject has been offered in blended mode (Biggs 1991) since Autumn 2001. Online assessment has been offered since that time.

Selected topics in ORM are expanded upon in Optimisation 1. The subject is strongly problem based and includes theoretical, numerical and computational methods. IMM introduces students to elements of linear algebra, complex numbers and single and multivariable calculus. It is undertaken by students from other degrees considering a submajor in a mathematical discipline. The software used in both subjects is the same as that utilised in ORM.

Assessment design

Assessment tasks, weights and timing

The types of assessment tasks and weights are assigned in the formation of subjects that occurs as part of the accreditation process. Teaching staff in a given semester must work within the types of tasks and weights specified in the accreditation documents. When designing the finer detail of the assessment tasks, consideration is given to the following questions: Does the assessment task:

- necessitate quantitative and qualitative responses?
- have a clear purpose and outcome?
- include models of an authentic situation?
- emphasise process as well as product?
- include collaboration?
- give students choices?
- link to subject objectives?
- include timely feedback mechanisms?
- encourage the appropriate, discriminatory use of resources? and
- enable students to examine and present different views?

(adapted from Northcote and Kendall 2001, p.921). Answers in the affirmative ensure that the approach adopted by students to assessment tasks contributes positively to learning outcomes. Not all tasks are expected to answer in the affirmative to each question rather the questions can be answered in the affirmative when the assessment tasks are considered as a whole.

Each subject has four components in the assessment design. The first assignment consists of a number of questions requiring written answers with working (10%). The class test is conducted online with emphasis on understanding the discourse and concepts of the subject, and on direct assessment of computer laboratory skills and their application to problem solving (20%-30%). In the second assignment the topic is chosen by the students and conducted collaboratively. It is usual for the task to utilise computational (and other) skills (10%-15%). The final assessment task is a proctored, closed-book examination, primarily sequestered problem solving (Schwartz, Biswas, Bransford, Bhuva, Balac, and Brophy 2000) (45%-60%). The contribution of these assessment tasks to the questions above can be found in Table 1.

Table 1. Assessment Design Criteria Checklist

	Quantitative and qualitative responses	Clear purpose and outcome	Includes models of authentic situations	Emphasises process and product	Includes collaboration	Gives students choices	Links to subject objectives	Timely feedback	Discriminatory use of resources	Eaxmine and present different views
Assessment task										
Assignment		✓	✓	✓			✓	✓		
Class Test	✓	✓	✓	✓		✓	✓	✓	✓	
Project	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Final Examination	✓	✓	✓	✓		✓	✓	✓		

From Table 1 it can be seen that the online test scores favourably in the design criteria, and contributes positively to the overall assessment design. The focus in the following sections will be on the online assessment component.

The test media
The Test Manager in *Blackboard* was used to develop the online tests. The Test Manager allowed the inclusion of a wide variety of question types including Essay, Multiple Choice, Matching, Short Answer, and True/False. Questions could be uploaded or selected from a Question Pool or previous online assessment. Question type, Question Text, Point Value, and answers are entered. An example of a File Response question with answer can be found in Table 2.

Answers and marking may be automated or require an external marker (in which case sample answers are provided) depending on question type. Feedback for correct and incorrect responses can be entered. Questions may be classified by category, level of difficulty, topic and keywords. This assists with the efficient re-use of items (Sjoer and Dopper 2002). When marking, the marker enters the Gradebook and selects the student test. The test appears with the automated questions marked. Other answers are marked on screen. Individual feedback can be supplied on a question-by-question basis. Marks, answers and feedback are available to the student after the marker submits the marked test.

Table 2. Example of File Response Question

Question
(a) Determine the solution to the linear program below using Excel. Save your file and click on "Attach" for the appropriate question, and browse to find the file.

maximise $z = x_1 + 2x_2$
subject to:
$4x_1 + 2x_2 <= 6$
$2x_1 + 3x_2 <= 4$
with,
$x_1, x_2 >=0$ and integers.

(b) For the problem in part (a), what impact (if any) would the addition of the constraint $x_1>=4$ have on the problem. (Briefly) explain.

Answer	(a)				
		x_1	x_2	lhs	rhs
		0	4/3		
	objective	1	2	8/3	
	constraint 1	4	2	8/3<=	6
	constraint 2	2	3	4<=	4
	nonneg1	1	0	0>=	0
	nonneg2	0	1	4/3>=	0

$x_1*=0, x_2*=4/3, z*=0$

(b) The problem would be infeasible because the largest value of x_1 that satisfies the other constraints simultaneously is 3/2.

The online assessment components

The tests started with no more than five multiple choice questions. These questions focussed primarily on demonstrating an understanding of the 'core of knowledge' which is 'particularly suited to online assessment' (Englebrecht and Harding 2004, p.219). Other items were primarily 'Essay' and 'File Response' questions. The Essay Questions emphasised problem solving, and solutions could be supported by written work. File Response Questions allowed students to submit files generated using the software of the subject – see the Question in Table 2 for example. These were marked online in the environment in which they were created. Assessment of these skills is something that paper-based assessment does artificially and quite poorly (Dowsing 1999).

Here then, assessment of knowledge, the lowest level in Bloom's hierarchy of educational objectives (Bloom 1956), as assessed by Multiple Choice Questions, is blended with the assessment of higher level attributes of Application and Analysis in the Essay and File Response Questions. The approach of blending question types is also in line with Heinrich and Wang (2003) where they suggest that multiple choice and matching questions 'are not sophisticated enough to examine students' understanding of complex content and thinking patterns' (p.768) The combination of human markers and computer-assisted marking is also complementary –

Human examiners are poor at simple tasks that require a high level of concentration whereas computer-assisted assessors are excellent at detailed, simple tasks but are poor at exercising judgement in complex cases since it is difficult to build 'intelligence' into a computer program (Dowsing 1999, p.133).

Implementing the online assessment tasks

The online tests were proctored, password protected and of fixed duration. They were held in the students' usual computer laboratory session so that no additional resources were required. A different password and test was used for each different session in a subject. When students took the test, all questions were made available simultaneously. This provided students with an overview of the test, allowed the questions to be attempted in any order, and ensured students were provided with the opportunity to review their answers prior to submission. The tests were open-book and open-source. This removed an artificial aspect of the assessment – students were no longer working without access to resources they would typically have if solving the problems in real life. That is, the sequestered nature of problem solving that is frequently a feature of mathematics tests (McLoughlin, Northcote and Marshall 2003) was removed.

A practice online test was supplied well in advance of the test date. Students could attempt this test in their own time and as many times as they liked. Feedback was set up for correct and incorrect responses. Soft copies of past tests and solutions were also made available. This provided students with the opportunity to familiarise themselves with the test environment, the structure of the test, and the nature of the questions. The practice and past tests provided valuable and immediate feedback to students, enabling them to address identified weaknesses in a timely fashion (Thelwall 2000; Erwin and Bailey 2002).

Stability of the technology was an understandable concern. At the beginning of the test, students were given instructions concerning what to do if they lost their test or if their computer crashed. To minimise the potential harm this event could cause, hard copies of the test were available. Files created outside the test environment are not subject to instability of the test environment, and hence do not suffer should the test environment crash. Students were also encouraged to save their files on the network drive. Submission of answer files through the digital dropbox could be undertaken for persistent failure of the test environment. It was helpful to have a spare computer in case a test needed to be reset or if a computer crashed.

A fundamental issue associated with online assessment in mathematics is the inherent difficulty in accommodating mathematical notation and structures such as proofs. A solution is to combine written work with online assessment. In the three subjects of this study, the submission of written responses was part of the online assessment task. There was no appreciable increase in marking time. Marks, answers and feedback were still provided online.

Staff and student perspectives

Staff perspectives
Greenwood, McBride, Morrison, Cowan and Lee (2000) list some of the advantages associated with the use of 'computer-based tests'. These advantages include reducing time commitments and the costs of distribution and marking of assessment tasks, facilitating the collation and allocation of student grades, the automatic generation of statistics, and greater security of computerised question banks relative to paper-based media. It was found that marking was no more time-consuming than marking a paper-based test – questions were easy to scroll through, uploaded answer files were easy to view, and marks were automatically added and made available to students. Feedback was individualised, easy to supply and immediately accessible to students. Further, copying appeared no more or less possible than for a paper test. In addition, question item banks provided a valuable record of the components of assessment and provide a library of questions. Online assessment also opened the possibility of accommodating the direct (and proctored) assessment of computing skills, and provided students with an authentic environment in which to problem solve.

Student outcomes and perspectives

Figure 1 below shows scatter plots of the online test versus the final examination marks for two of the subjects. It can be seen that the majority of students perform better in the online test (vertical axis) than in the final examination (horizontal axis). This is in agreement with Englebrecht and Harding (2004, p.228). This result however, may be biased as students with close to passing grades or passing grades prior to the final examination may have elected to place less effort in the final examination than may have been the case otherwise. Further, the two tests assess largely non-overlapping objectives, and hence performance in one task may not be indicative of performance in the other.
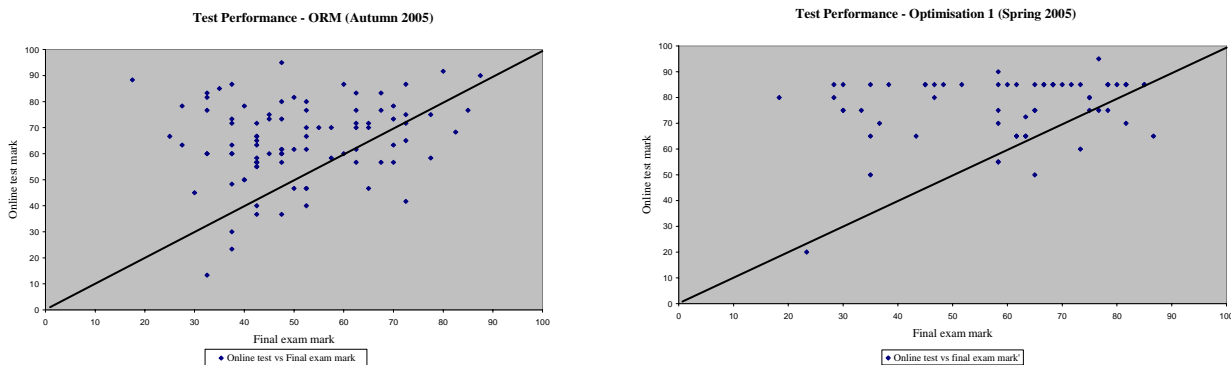

Figure 1. Test Performance

A survey of the views of students was conducted after the students had completed their final examinations. Students were asked to indicate whether they agreed (represented by an upper limit of 1) or disagreed (a lower limit of 0) by marking the extent of their agreement on a line segment. Unlike the study of Englebrecht and Harding, evidence suggested that students did not demonstrate a preference for online assessment (mean 0.501, standard deviation 0.241, sample size $n=93$). They showed a slight increase in preference for a combination of paper-based and online assessment (mean 0.5767, standard deviation 0.1928, $n=93$). A possible explanation may be that 'Students … carry with them the totality of their experiences of learning and being assessed' (Boud 1995, p.37). Students' experiences with paper-based assessment are then likely to dominate their assessment experiences. The result here may then reflect their preference for the familiar. Also unlike Engelbrecht and Harding there was not a finding of reduced examination stress (mean 0.5352, standard deviation 0.2353, $n=93$).

Students' responses to the value of the practice test to them were positive (mean 0.6698, standard deviation 0.1513, $n=93$). Positive responses were also noted for the open and authentic nature of the online assessment (mean 0.6380, standard deviation 0.2265, $n=93$). Further, they felt that this open access lead to improved marks for the task (mean 0.6150, standard deviation 0.2036, $n=93$).

Conclusion

Computer technology has come to play central roles in both learning objectives and instructional environment in tertiary mathematics. While the use of online assessment may seem a logical progression in this regard, it is perhaps not as widely used as it could be. Online assessment can be a valuable investment with efficiencies in marking, administration and resource use. Appropriate design of online assessment tasks and support activities can also foster other positive learning outcomes including competence in the use of, written and electronic communication, critical thought, reasoned arguments, problem solving, and information management, as well as the ability to work collaboratively. Further, online assessment offers an authentic environment under which to assess the

computer laboratory skills that feature strongly in many mathematics subjects and in professional practice. Students respond positively to this aspect of the assessment and felt that this lead to better marks. There is qualified support for this student conclusion.

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