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Mathematics Assessment at a Distance

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Mathematics Assessment at a Distance

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Abstract: This article considers the development of a Web-based assessment system by which remote students take a credit-bearing test online at the end of the Open University 'Maths for Science' course. During the test the students receive immediate, targeted feedback on their answers, and are awarded a mark that reflects the amount of help they have been given.

1. Introduction and Context

This article describes a project pioneering the use of Web-based assessment with instantaneous feedback for students on an Open University (OU) course entitled Maths for Science. This course, which is at level 1 and carries 10 CATS points, was written to give students confidence and practice in the mathematical skills needed for OU Science Faculty courses. It assumes only basic arithmetic and revises topics such as the addition and multiplication of fractions, before introducing students to algebra, graphs, trigonometry, logarithms, exponentials, probability, statistical hypothesis testing and differential calculus. In addition, the focus on maths 'for science' means that topics such as the correct use of scientific notation, significant figures and SI units are developed throughout the course. As is the case for most OU courses, Maths for Science has no entrance restrictions, although plenty of advice, including a diagnostic quiz, is available for prospective students to help them decide whether the course is suitable for their needs. The course material consists of a book of specially written teaching material, which includes worked examples and self-assessment questions with full solutions. There is also a set of supplementary questions, again with full solutions, for further practice, a Study Guide and a CD-ROM. Students work on the course at home, with no face-to-face tuition or meetings with fellow students. However, learners in need of help can telephone specialist study advisers, and a text-based computer conference is also available for those who wish to have asynchronous discussions with fellow students or the advisers. A website allows the Course Team to post urgent information, errata or additional comments, and gives students access to the online assessment. The University Computing Help Desk offers technical assistance to all students and advisers.

The 10 CATS points courses in the Science Faculty Short Course Programme are presented four times per year, and recruit large student populations. Maths for Science was presented for the first time in September 2002 and more than 1300

students have registered on one of the first four presentations. Students can opt to spend either 8-10 weeks or 4-5 months on the course.

Credit for science short courses is awarded on the basis of a single End of Course Assessment (ECA), which is completed by the students at home, as an open-book, untimed piece of work. At level 1, grades are simply 'pass' or 'fail', and although the 10 CATS points may be included in degree profiles, they are not taken into account when awarding the degree classification. The marking and administrative processing of such large numbers of ECAs means that students do not get their result for about 8 weeks and with a paper-based, hand-marked ECA, students are given only rather general feedback on their performance. This system was not felt to be appropriate for the subject matter of Maths for Science; the Course Team wanted to be able to give students clear and rapid feedback on their strengths and weaknesses. The decision to use an online ECA was made largely because this provides a means of giving feedback to students that is instantaneous, meaningful and personal.

The next decision was that the feedback would take the form of tuition, so that students who made mistakes could be helped to work out the source of their error and then be given another attempt at the question. Students would be allowed up to three attempts at each question, with the mark awarded decreasing with the number of attempts and thus with the amount of feedback given. The award of such 'partial credit' is recognised as an important feature when computer-assisted assessment is used summatively [1].

Maths for Science is the first Open University course to have interactive online summative assessment that awards partial credit following feedback. In this paper the project and its outcomes are described, and some of the difficulties encountered and spin-off benefits are considered.

2. Background to the Project

Computer Marked Assignments (CMAs) have been a feature of the Open University's assessment system since its earliest days. In their original form they were multiple-choice assignments, delivered to and returned by students through the postal service, and answered on forms that could be machine-read. A reduction in the amount of summative assessment, together with the widespread use of home computers in the 1990s gradually brought changes. Within the Science Faculty it was decided to develop interactive, formative assessment, delivered to students by CD-ROM. This enabled the construction of a wide variety of interesting questions to stretch the students' abilities. They could include still or moving images and – most importantly – could correct

misunderstandings there and then. An evaluation in 1998 of student reaction to these interactive self-assessment questions showed them to have been well received [2].

At that time, the commercial packages and assessment systems being developed in other universities were aimed largely at enabling the testing of performance, with feedback and hints taking a lower priority. The OU approach has always emphasised the teaching and learning value of assignments, alongside their assessment purpose. There was also a desire within the Science Faculty to move beyond the constraints that multiple choice questions had imposed on OU CMAs for the previous twenty-five years. For these, and other, reasons it was decided to develop an OU Science library of question types and, to this day, this question bank continues to be expanded.

By the time the Maths for Science assessment was being planned, OU students could be expected to have access to an Internet connection (usually in their own home, but if not then from work, a library, internet café or friend's house), and the University was keen to take the next step of delivering 'assessment with feedback' online. After a number of years spent developing, evaluating and using the formative CD-ROM assessments with tens of thousands of students, we were confident that the questions, the answer matching and the feedback required for the Maths for Science online assessment could be written using the OU library of question types and assessment framework. In particular, we could see how to generate parts of the questions randomly, so that different students would get different forms of the question, and how to write sophisticated answer-matching algorithms that would enable targeted feedback to be provided.

As well as fulfilling the primary aim of embedding fast, meaningful feedback within the assessment process, the introduction of an online ECA system was also seen as economically desirable, removing the expense of marking large numbers of scripts by hand. Templates and question types can be reused, and when appropriate, random-number generation can produce many questions at minimal cost.

Finally, but importantly, institutional data-processing systems were already in place to ease the passage of the Maths for Science assessment. To ensure that only bona-fide students registered on the course could access the ECA, students could be routed through the University's existing password-protected authentication system. Furthermore, systems to receive the data from the ECA were already in place. The University has always used a data-processing system to handle assessment scores for all students and all courses, and to provide the

detailed analysis by individual and by cohort required for examination and award boards. All that was needed for this project was a means of securing the data from the online transactions and transforming them to fit the existing processing systems.

3. Designing the Assessment

It is widely acknowledged (see, for example, Beevers and Paterson [3]) that computer-assisted assessment in mathematics and other numerate disciplines faces two particular challenges:

- Ease of input of mathematical expressions; and
- Answer matching which recognises several responses as 'equally right' or 'equally wrong'.

In designing the Maths for Science assessment, ease of data input for students was a primary concern. It was not considered desirable to supply specialist software capable of dealing with mathematical expressions, as students would have had to invest too much time in learning how to use it. It proved impossible to do without superscripts (for exponents), so a special button has been provided to enable students to enter these. Other than this, all that is required is the use of the alpha-numeric keys and the symbols +, -, (letter) x and /. Figure 1 illustrates a typical question, a student response and the corresponding feedback.

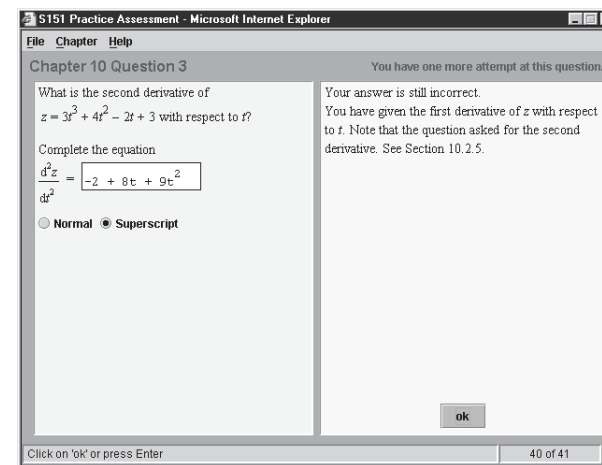


Figure 1: A simple differentiation question, with targeted feedback

The academic authors were particularly anxious that students should not be constrained as to input format, so answer matching must cater for equivalent responses. For example, if the expected response to a question is $3.45 \times 10^2 \text{ ms}^{-1}$, a response with the units input as m/s must also be marked correct. Similarly, if students choose to input the answer as, say, $3.45 \times 10^2 \text{ ms}^{-1}$, $3.45\text{e}2 \text{ m/s}$ or, depending on the learning outcomes being assessed, perhaps even as 345 m/s , these should also be marked correct. In some questions (for example if students are asked to find the gradient of a graph) it is only fair that a range of numerical responses should be considered to be acceptable. Furthermore, it is not only answer matching for correct responses that needs to recognise alternatives. The targeted feedback shown in Figure 1 must be triggered irrespective of the order in which the terms are input, and whether or not the student enters spaces between the terms.

The Course Team, like others (see, for example, Lawson [4]), recognises the difficulties inherent in the use of multiple choice questions for summative purposes, so as many questions as possible have been designed to require free-input answers. However, a few multiple choice questions have been used, on occasions when the data entry would be too complex or the question type particularly lends itself to this format. In designing multiple-choice questions, great attention has been paid to the distractors; by trying to ensure these correspond to common misunderstandings, the learning benefit of the feedback can be maximised [5]. Figure 2 shows a typical example of a Maths for Science multiple-choice question, with feedback. However, as shown in Figure 1, the use of targeted feedback has not been limited to multiple-choice questions.

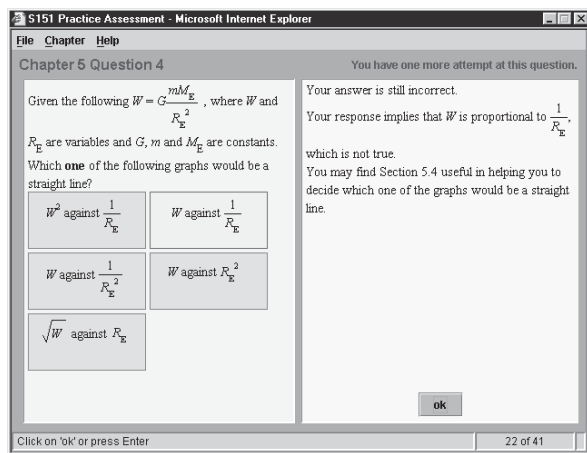


Figure 2: A typical multiple choice question, with targeted feedback

To limit opportunities for plagiarism most questions have been designed in several variants that are randomly selected. However the scientific context of the mathematics being assessed means that true random-number generation can only be used with caution. The fact that the assessment is summative means that care must be taken to ensure that different variants of a question are of similar difficulty. For example, correctly rounding an answer up from 3.456 to 3.46 is arguably a more difficult skill than rounding an answer down from 2.591 to 2.59; expressing an answer of 5.893 to two significant figures (5.9) is perhaps easier than expressing an answer of 7.998 to two significant figures (8.0).

Students are allowed up to three attempts at each question and they are told, at each stage, how many attempts they have remaining. For many question types, an incorrect response at the first attempt generates the simple feedback 'Your answer is incorrect'. This gives students the opportunity to spot the nature of their error for themselves. However, some error types have special feedback at this stage. For example, if a student picks some correct and some incorrect options in response to a multiple choice question, they are told how many of the options they have selected are correct. If the question requires the input of a unit of measurement (e.g. cm, kJ or MW) and a student uses the wrong case for the unit, they are told explicitly. If a student has correctly calculated the value of a physical quantity, but expressed it to an inappropriate number of significant figures, this is explained. Figure 3 illustrates the feedback given when, at the first attempt, a student has correctly calculated the answer, but has expressed this answer to too many significant figures and has omitted the unit.

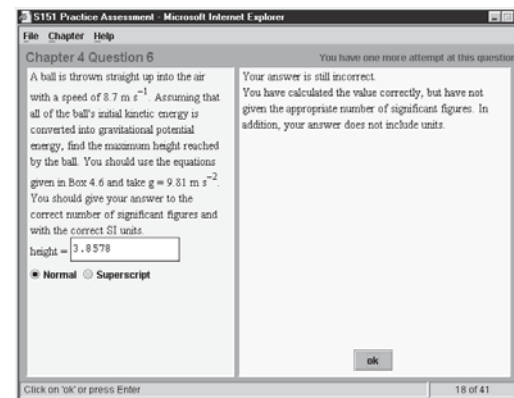


Figure 3 The feedback given in response to an answer given to too many significant figures and without units.

The feedback after a second incorrect response is similarly targeted whenever one or more specific errors are clearly responsible. In addition, feedback at this stage, in response to any incorrect answer, becomes more detailed, usually providing a hint as to how to proceed and a reference to the relevant section of the course text. Figure 1 and Figure 2 show feedback typical to this stage. After the third incorrect attempt at a question the student receives a detailed explanation of the correct answer.

The Course Team, like others (see, for example, Pitcher et al. [6]) considers it to be important to give students an opportunity to familiarise themselves with the technology, the question formats and the input methods for their answers, so a Practice Assessment (PA) was also developed, which students can access throughout the course. The main difference between the PA and an ECA is that students can attempt the PA as many times as they wish, with different numbers and variables being generated on each occasion. In the original conception, the PA questions, like those in an ECA, had to be attempted in order. However, this stance was modified in the light of student comment; this is discussed in Section 5. Students are encouraged to attempt the PA early in their studies, partly as a method for checking that they can indeed access the assessments, but also as a confidence booster.

An ECA contains 35 questions; the PA has slightly more. The Course Team has the option of specifying thresholds or differential weighting for different questions and sections, all of which can be handled by the University's central data-handling systems. The ECA is made available to students for the final three weeks of each presentation. Within that time period, students can spend as long as they like on the assessment, though they are advised that it will typically take about 3 hours.

Although the assessment was to be delivered and submitted online, it was recognised that many students might want to work out their answers on paper before inputting them; indeed they are encouraged to do so if necessary. This might take time, especially if a student needs to check back with course material or enter a lot of data into a calculator. It was therefore essential to make it clear to the students that they could voluntarily close down the connection while working on a problem. The software designers had to ensure that in such an event, or if the line were lost because of a technical problem, the assessment would restart at exactly the point at which it was abandoned.

At the end of the ECA, students are given a summary of their correct and incorrect responses and are then offered the opportunity to 'submit' their work and hence to complete the course.

4. Implementation

The Open University requires its students to provide their own computer and internet connection, and tries to keep the specification to a minimum. For Maths for Science this was set at Windows 98, Pentium III 400 MHz, with 32' CD-ROM. In terms of the online capability, the defining characteristic of the assessment software was that it should be capable of operating satisfactorily over a 56 kbaud modem. The Maths for Science assessments run as Java applets within a browser on the student's machine. Internet Explorer can be installed from the Course CD-ROM if it is not already on the computer being used (Netscape can also be used), and the Java Runtime Environment can be installed either from the Course CD-ROM or the Internet. Having authenticated themselves with the University computing system, students connect to the Maths for Science website and download the applet.

In earlier developmental work, different options for delivering questions to students had been investigated. From this it had been found that a single download at the beginning led to a more satisfactory user experience, so this was the system used for the Maths for Science assessment. Initial estimates were that an ECA of 35 questions should typically take 2-3 minutes to download on a 56 kbaud modem; were the student to choose to take a break and reconnect at a later time, restarts would be much quicker. The small amount of traffic that has to be sent whenever an answer is checked and feedback returned is of the order of 100 bytes. The software designers' hope was that these numerous mid-program transactions would be usually completed in a second or two and that this delay would not be too long to interrupt the flow of the assessment. Early trials with a small number of volunteer students showed these estimates to be accurate. Equally importantly, calculations also showed that the server-side software could cope with of the order of 50 such transactions per second on the server platform available in 2002, indicating that the system was scaleable to the anticipated student population.

When work started on the Maths for Science assessment, there was already in place a large 'class library' of question types that could, in the language of the object-oriented programming community, be 'inherited'. This means that once a question type has been written, it can be re-used with little fuss. The format and style of the questions follow a well defined order: a question, a response-matching function that incorporates a feedback module, and an answer. The inter-relationships and behaviour of these objects are inherited from existing classes; the first and last items are used just once per question, while the response-matching section can be cycled around as required. For Maths for Science it was very important to build on the use of these existing question

structures, yet at the same time to have available the mathematical constructs that come with programming languages. The response-matching functions for Maths for Science are extensive and have taken a considerable proportion of the development effort. The 'accuracy settings' of the CUE system [7] and the use of string evaluation [6] are both illustrations of techniques known to the authors, though only the former were incorporated into the Maths for Science assessments.

In the initial stages of the project, there was considerable interaction between academic authors and software designers and it was only when the first complete set of questions had been produced that it was possible to start rationalising the process; this resulted in quite detailed guidelines that all could follow, a set of repeatedly used behind-the-scenes software routines and increased authoring efficiency.

The transaction-processing module to communicate between the application on the students' PCs and the university server was developed specifically to ensure that all attempts at individual questions were securely recorded; that the client and server remained synchronised; that students could not revisit questions they had already completed; that reconnections following a break would return a student to the exact position they had reached on their previous visit; and that any random numbers could be regenerated such that if the connection was lost the same set of variables would appear on reconnection. The transaction processor had to be capable of communicating with the server in a suitable time frame over modem lines from all over the UK and other EU countries, and be reliable and robust in the event of the inevitable communication breakdowns somewhere along the network. Finally, the data from the online transactions had to be equally securely transferred to the University's existing processing systems for examination and assessment scores.

5. Outcomes

5.1 Technical issues

Delivering online assessments to students' home PCs is inherently risky. The Maths for Science assessment has to sit on top of a wide variety of hardware and software. For traffic through modems to the telecoms network using assorted ISPs, to the university server and back again, there are innumerable potential problem points. There is nothing more frustrating for a student than technical issues stalling their academic work, so all technical problems are taken very seriously. Students are encouraged to attempt the practice assessment early in their studies, largely to check that the technology is working as

it should be, and they are also encouraged to complete the ECA well before the deadline. Alternative provision is in place in case of intractable technical problems. However, the assessments have proved to be satisfactorily robust.

The Course Team and software developers are confident that they dealt satisfactorily with all the queries of a technical nature brought to their attention whilst the ECAs were live, and all of the students who raised these queries went on to complete the ECA online. Most student queries, for example those about installing the Java Runtime Environment and those concerning data input, have been very straightforward to resolve, often simply by referring the student to the course's Study Guide. A few technical problems, for example when a student's computer failed to display minus signs, have required more detailed investigation. This particular problem was traced to a corrupted font file on the student's PC. The Open University Computing Help Desk reported four difficult technical issues from the first two cohorts and does not regard Maths for Science as a problem course. Further evaluation is underway to find out whether any students gave up because of problems with technology, either because they did not seek help from the University or because the help they received was inadequate.

As for the software that handles the communications between the client and the server, a dozen server-side inconsistencies in the student data were recorded during the first ECA (from 10,000 transactions), but by the second presentation these had been successfully reduced to zero. The transfer of marks to the University's data-handling system for exams and assessment has worked exceptionally well, providing useful information to the Course Team and allowing the option (not needed so far) of altering parameters in the event of rogue questions or other unforeseen problems.

The project's worst technical problems have been unrelated to the Maths for Science software and have been the result of campus-wide power cuts in Milton Keynes and malicious virus attacks, both of which have led to the university servers being unavailable for periods during busy weekends. However the availability of the ECA for three weeks helps to mitigate such problems, and although these periods of unavailability were very inconvenient to the students, they do not appear to have impacted on the number of students submitting their assessments.

5.2 Pedagogical issues

The fact that a full record of connections and inputs made by each student is automatically stored means that all aspects of the students' work on the ques-

tions can be analysed in detail. Although such analysis is carried out for each course presentation and question, the statistical results presented here relate to the second ECA, corresponding to the largest student cohort to date. However, trends have so far been similar for all cohorts.

Students are making good use of the Practice Assessment (more than 90% of students who attempted the ECA had tried the PA first) but the way in which they use it varies. Some students spend just a few minutes on the PA prior to starting the ECA, presumably to get a feel for the interface. Others make extensive use of it, working through each question many times (with different data-sets each time) presumably to give themselves an extra bank of questions for practice, in addition to the printed supplementary questions. One student spent nearly 24 hours active time on the PA, working through it a total of nine times. It is reassuring that this student passed the course.

The Course Team's original estimate of the time required to complete the ECA was reasonably accurate. Students spent an average of about three and a half online hours on the ECA. However, this average figure conceals a huge variation, from those who spent less than one hour to one student who spent over ten hours online working on the ECA. There is a corresponding variation in the number of separate sessions spent on the ECA (from 1 session to 22, with a median of 4) and in the total elapsed time from a student starting the ECA to pressing 'submit' (from 48 minutes to more than 18 days, with a median of 1.3 days). There is no obvious correlation between the amount of time spent on the ECA and a student's success. There are both low and high scoring students amongst those who spent less than an hour on the ECA, and two students who spent more than 10 hours on it both passed. Not surprisingly, there also appear to be a few students who might have been well advised to spend more time on the assessment.

It is encouraging from the teaching and learning point of view to find that many students are getting questions right at the first opportunity. As might be expected, there is also a strong correlation between the number of questions right at the first attempt and overall success in the ECA.

Analysis is underway, on a question-by-question basis, of how much use has been made of the feedback provided to students. Given that the primary pedagogic driver for introducing this form of assessment was the provision of meaningful teaching feedback, it is interesting that in many questions a substantial number of the students getting answers wrong at the first attempt manage to give the correct answer at the second attempt, even when the feedback is minimal. For example in a question that required students to calculate the

estimated standard deviation of a population (s_{n-1}) from values given for a sample, 78% of students gave the incorrect answer at the first attempt, mostly because they calculated the standard deviation of the sample itself (s_n). However nearly half of these got the answer right at the second attempt, even though the only feedback that had been given was 'Your answer is incorrect'. This suggests that many students are capable of catching their own slips and small errors, yet neglect to do so routinely.

In some cases, it is clear that the targeted feedback given is very successful in guiding students to the correct answer. For example, in a question which asked for an answer to a specified number of significant figures, two thirds of those who were wrong at the first attempt were only wrong because they had given the incorrect number of significant figures. The targeted feedback enabled all of these students to give the correct answer at the second attempt.

The question types used in the assessments are constantly reviewed in the light of student performance. In addition, the management information available to the Course Team (about which questions are answered well and which questions are answered badly, and in what way) has been a useful by-product. As a result of this two small sections of the course text have been re-written and additional supplementary questions in areas of frequent misunderstanding have been supplied. The information is also contributing to the Course Team's knowledge of student misconceptions. Many of the student errors have come as no surprise; however there have been some unexpected findings, and some errors would not have been recognised as anything other than slips were it not for the large amount of data available. For example 9% of all students (50% of those who got the question wrong) gave the answer 243 when asked to evaluate the expression $(3^6)^{1/3}$. Evaluation of other expressions of the type $(x^m)^{1/n}$ resulted in similar and frequently occurring wrong answers. These responses were puzzling for a while, as it had been expected that students' reasoning would be as follows:

$$(3^6)^{1/3} = 3^{6 \times 1/3} = 3^2 = 9$$

It was eventually realised that the error was caused by (incorrect) calculator use; students had entered, $3^6/3$ which gives 243.

5.3 Student reactions

The first cohort was surveyed by postal questionnaire as part of a wider evaluation of the courses in the Science Short Course Programme, and anecdotal evidence has been gathered from messages posted on the course conference

and from direct communications from students.

Students reported using the Practice Assessment both as a practice for the ECA and as a bank of additional questions, with most regarding the former purpose as more important. Use of the PA clearly boosted students' confidence in their understanding of both the course material and the computer interface.

More general feedback from students about the assessment strategy provided much food for thought. There were many complimentary comments, supporting the Course Team's original aims, for example: 'Perfect for distance learning'; 'I found submitting the ECA on the web was very convenient'; 'The ECA worked well, the immediate feedback was ace'; 'Very useful to be able to stop/start the assessment to fit in with other commitments'; 'I had never touched differentiation before and when I got the questions on it ... correct I felt as good as if I had won the lottery!' Additionally, it was gratifying that several students reported the ECA to have been 'fun'.

There were also a number of suggestions for relatively minor ways in which the assessments might be improved, and several of these led to changes being implemented for subsequent ECAs. For example, small technical modifications have been made to ensure that students (especially those with dexterity problems) are less likely to press the 'pass' button by mistake; to provide a choice of background colour (particularly useful for students with dyslexia); and to send an even clearer indication to students that their ECA has been 'received' by the University.

Despite the fact that students said they used the PA mainly as practice for the ECA, many students clearly wanted the PA questions to be accessible in the order of their own choosing, and to be repeatable without having to work right through the assessment first. The team has now reconfigured the PA to comply with these requests, such that the questions can be attempted in any order and repeated at will with either the same or different variables. The desirability and feasibility of making similar modifications to the ECA are being considered.

Some students felt that they were penalised for 'silly mistakes'. In reality, the full record of inputs is inspected in borderline cases and minor data-entry slips are considered sympathetically; the Course Team has realised that this needs to be made clearer to students in advance. It is also the case that slips would be penalised – albeit in a different way – in a script-marked assessment, and in the Maths for Science ECA the instantaneous feedback on each response should enable the students to recognise and possibly correct their errors. The Course

Team would like to be able to investigate the effect of medium and question type in a systematic way, as Fiddes et al. have done [8], but in the meantime, the detailed inspection of all borderline cases assures confidence in the results of the online assessment.

The latest cohort to have completed Maths for Science is receiving a postal questionnaire specifically about the assessment. As mentioned previously, this asks questions about technical issues; it also asks about students' use of the feedback provided and their feelings about Web-based assessment of this type. For example, all students (whether they submitted the ECA or not) are asked whether they have worries about the cost of working online. Although a phone bill for three (or even ten) hours online is small compared with the typical cost for an OU student to get to an examination centre, the Course Team is conscious that a heightened awareness of the costs of being online could cause some students to rush the assessment.

Many of the suggestions for improvement that have come from students have been incorporated, and such ideas will continue to be considered seriously. However, it is not possible to accede to all suggestions without compromising the special nature of the assessment. Rather than trying to make the Maths for Science ECA appear like the forms of assessment already in use within the OU and elsewhere, the Course Team will therefore seek to emphasise to students the positive aspects of the format, in particular the instantaneous 'intelligent' feedback.

6. Conclusions

The Web-based assessment has given the Maths for Science Course Team a method of accurately assessing students' ability without the effort and expense associated with marking many hundreds of scripts by hand on a regular basis. The huge amount of data automatically available from the assessments has enabled the Course Team to improve both the assessment questions and the course itself, and this process of refinement will continue. Students are provided with instantaneous and meaningful feedback on their answers as they go along, and a mark is awarded that accurately reflects the amount of help they have been given. Furthermore, many students seem to have enjoyed the experience.

However, the effort expended in getting these assessments up and running has been substantial and can only be justified by setting it off against the large number of students (expected to rise to 1500 - 2000 per annum) and the long term savings in staff time. It also remains to be seen whether the benefits of the

'assessment with personal feedback' model offer genuine improvements in student understanding and retention. Should that indeed be the case, the University can be expected to commit to further online assessments in the mode pioneered by Maths for Science.

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