Using online randomised quizzes to boost student performance in Mathematics and Operations Research

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***Abstract*— The use and development of online tools for learning in mathematically based disciplines is flourishing. This has occurred in reponse to the need to provide flexible learning choices for cohorts of students having a wide range of mathematical backgrounds, often insufficient for their chosen fields of study. Many students have difficulty with detailed written assignments which contain substantial amounts of mathematics, and need to be given extra incentive to spend time doing the necessary preparatory exercises.**

Furthermore, it is necessary that students revise previously learned concepts, preferably without using up valuable lecture time. Students need encouragement to do this, rather than trusting that they will magically remember what is needed along the way. To make such preparatory and revision work compulsory means assessing it in some way, which is an insurmountable task to do manually, but well suited to a computer.

The importance of providing timely and accurate feedback to students regarding their progress cannot be underestimated. However it is impractical to provide this feedback to large classes unless either plenty of staff, or an automated system, is available. With appropriate feedback, students are more likely to do more than the minimum requirements, and so their achievement and interest in the subject will be enhanced.

The MacQTEX online quiz project ([1], [2], [3], [4], [5]) was developed in the Department of Mathematics, Macquarie University, Sydney, and for the past three years has been used for formative assessment in undergraduate mathematics units. Following its success in improving students' learning outcomes, in 2005 the Department of Statistics introduced it in an elementary Operations Research unit.

Quizzes are presented online as interactive PDF documents. Students may repeat a quiz as many times as is necessary to achieve a passing score, thereby getting valuable practice. Randomisation of numerical parameters and other aspects of the questions means that each instance of a quiz is different. A quiz is marked on submission to the server and students receive immediate feedback. At this time detailed solutions are revealed, which, rather than being general solutions, use the actual random parameters of each question instance.

Question types include the usual multiple choice, multiple response (the correct answer is comprised of several choices), and fill-in-the-answer style. The latter may take a numerical answer, or a mathematical expression. Equivalence of mathematical expressions is recognised, so answers such as $\sqrt{x}$ and $x^{1/2}$, for example, are both acceptable.

With the use of a system such as MacQTEX, it is possible to begin to overcome some of the difficulties of teaching large classes. In such classes it is easy for students having marginal interest or ability to fall behind, or to feel anonymous and isolated.

It is an interesting contradiction that the introduction of an automated system can encourage student contact with a real live staff member, particularly in the case of students who would not normally approach a lecturer or request help with their learning.

In this paper we describe the MacQTEX quiz project itself, and the positive effects it has had on student performance and behaviour. We describe the ways in which quiz system makes it possible to identify struggling students early in the semester, and the action that can then be taken, giving these students the sense that their lecturers care that they succeed.

Additionally we discuss how the system provides teaching staff with an immediate indication of the level of understanding the students have reached. If necessary, more time can then be spent on topics that have been more challenging for the students than expected.

I. INTRODUCTION

The studies of mathematics and statistics at university present several difficulties, to both students and staff. Large numbers of students, engaged in a variety of disciplines, need to study mathematics and statistics to a certain level. Many of these students have left school with at most elementary mathematics. Yet, in a short time after entering university, they are expected to achieve a certain level of proficiency in order to support studies in their chosen area. Hence a cohort of students, particularly those in introductory mathematics and statisics units, may not be particularly motivated or interested in the unit per se. Rather, they view the unit simply as a requirement which they would prefer to avoid, rather than something from which they will benefit in the longer term.

New students also arrive at university several months after having left school, which is enough time for much of what they learned in order to gain a pass in mathematics to have been already forgotten. This is also true of students already at university, who either have forgotten the mathematics and statistics they have crammed for their most recent examination, or have not studied it in consecutive semesters. Hence there has not been sufficient reinforcement of the concepts that they will be assumed to know thoroughly for the next unit. Clearly

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there is a need to encourage students to undertake a certain amount of revision. Yet there is too much new material to be learned for lecturers to devote the first couple of weeks of lectures to such revision. Besides, this would most certainly be highly off-putting to those students who have already attained the expected proficiency.

In addition, students often fail to appreciate the importance of working on routine problems for practice, or in fact doing anything that is not compulsory, or that is not assessed in some way. It is not possible to provide sufficient amounts of practice material in written assignments or tests, as marking the papers then becomes an insurmountable task. In any case, by the time marking is complete and the assignments or tests are returned, students will often simply look at their marks and quickly browse through their work, but not really attempt to understand their own errors, or the finer points mentioned in the printed solutions which have been provided.

By including tasks such as randomly generated online quizzes, many of the above problems can be addressed, particularly in the large classes typically seen in units which support several other disciplines. Students are given immediate feedback on their work, they must make the effort to understand the solutions in order to pass the quiz, and they may do the work in their own time. Quizzes can be used to enforce revision, and to reinforce new concepts and techniques as they are being taught. In addition, staff time is not taken up with large amounts of marking and the associated administrative tedium.

There are many online learning tools and quiz systems now in existence. Many of the large commercially available systems, such as WebCT and Blackboard, are designed to encompass as many subjects areas as possible, as these systems are intended to be installed at University level. Whilst they have enormous functionality, it is not always suited to a discipline such as mathematics, which has specific demands of such a system, but for which many of its functions may be superfluous. On one hand, presentation of mathematical notation in online exercises is a major problem, but facilities such as bulletin boards and chat lists are useless to mathematics students, as they have no way of exchanging intelligible mathematical expressions.

The number and variety of online learning and assessment tools for mathematics is growing rapidly [1] Common problems are faced by developers of online mathematics quiz systems. These include the challenge of presenting mathematical notation on the web, how best to assess a student's answer and provide useful feedback, and the difficulty of automating the process of designing randomised questions. All of this must be achieved whilst preserving an environment that students find relatively easy to use and quick to respond.

To address these issues, many online tools use large computer algebra systems, such as Maple, to process mathematical content. Others, such as MacQTEX, opt for open source software to support the system. Most present material on web pages, and process student's responses at the server. A few implement client-side processing, and a small number produce interactive PDF documents. Randomisation of questions is achieved in various ways, such as choosing from an existing bank of questions, requiring the author to provide a set of alternatives, or by generating random parameters on the fly.

The outline of this paper is as follows. Firstly, a detailed description of the MacQTEX quiz project will be presented, including the types of questions available to students and the comprehensive tools provided for quiz and class management. Later, there will be a discussion of the use of online quizzes as a learning tool, in which their effectiveness in formative assessment and their affect on the level of understanding gained by students is considered. Finally the future development plans for the MacQTEX quiz project will be outlined.

II. THE MACQTEX ONLINE QUIZZES

A. *Quizzes and question types*

A MacQTEX quiz is presented as a PDF document containing form fields similar to those one would see on a standard web page [3], [4], [5]. The processing of these fields is controlled by JavaScript [6], equipping the quiz with a fully functional interactive interface. All processing of a student's answers and calculation of scores is self-contained. This provides much faster operation than in many other quiz systems, which contact a server for every action the student takes. A further advantage of client-side processing is that a student may review and change answers at any time until the completed quiz is submitted to the server.

Each time a student requests a quiz, it is different. Every question allows a certain level of randomisation. This is designed to provide sufficient variety that the correct answer is not too obvious until the student has seen the question many times. Randomisation may be applied simply to numeric parameters, or may affect the form of mathematical expression used; such as the choice of a function, the invertibility of a matrix or the scenario relating to a data set.

Question types include the usual multiple-choice, multiple-response (in which the correct answer may be comprised of a particular combination of choices), as well as fill-in-the-answer types, as shown in Figure 1. These latter may be numeric, text or a mathematical expression. Questions with several parts, all of which use the same random parameters, can also be generated. Since the answers to such multi-part questions are inter-dependent, a student may choose to check his/her answer to an early part in order to be sure of using correct information for subsequent parts, see Figure 2. Having done so, that answer may no longer be changed.

The processing of fill-in questions allows equivalent mathematical expressions to be recognised. However, it is possible to allow or disallow certain types of notation. In a question on trigonometry, for example, it may be desirable to exclude decimal answers, to prevent students simply entering something from a calculator instead of working out the answer using triangles and quadrants.

[1]Detailed discussions of some of the latest developments can be viewed at http://mathstore.ac.uk/articles/maths-caa-series.

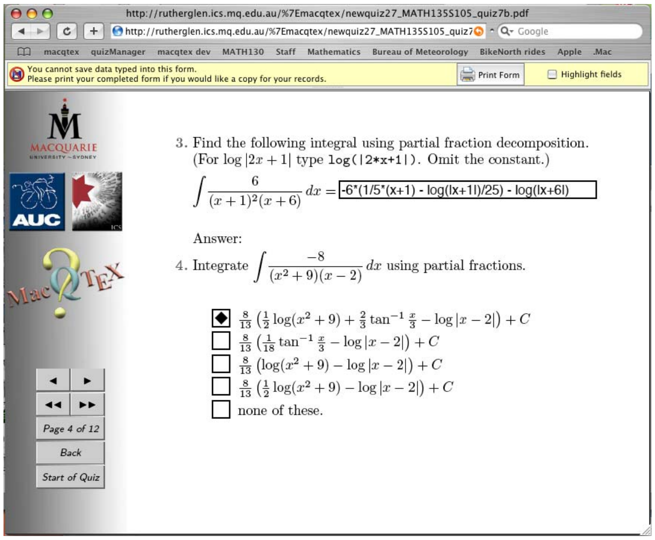

Fig. 1. Typical quiz questions, showing a fill-in-the-answer question and a multiple choice question.

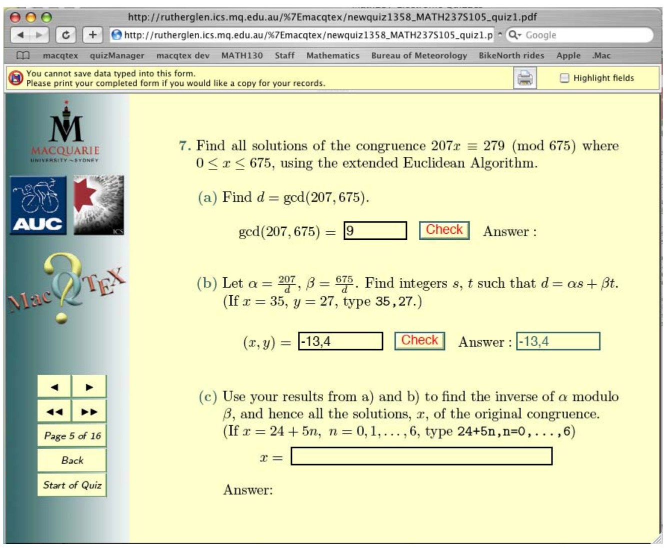

Fig. 2. A multi-part question, in which the student has checked his answer to part (b).

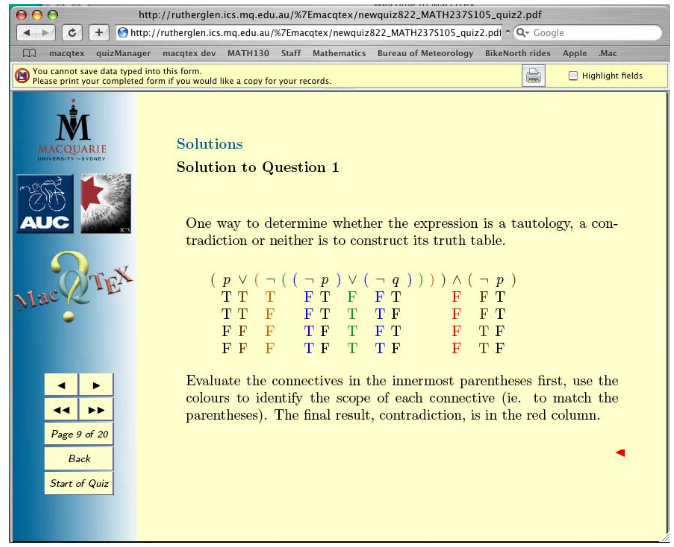

Fig. 3. A fully worked solution based on the question's random parameters.

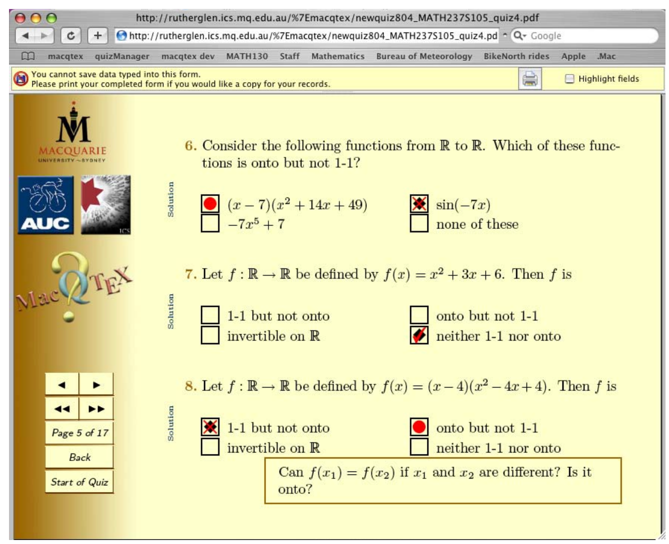

Fig. 4. A hint appears when the cursor is passed over the incorrect answer choice. This hint asks the student to think more deeply about the problem.

On completion and submission of the quiz, the score is calculated and the correct answers are revealed. Fully worked solutions become accessible, having previously been hidden. For multiple-choice questions, hints become available. These are designed to suggest a possible error in the students thinking that may have led to the wrong choice having been made. The solutions, such as the example shown in Figure 3, and many of the hints, are based on the specific parameters that were randomly chosen. They are not just general solutions, leaving the student to reconstruct the solution from the model, a task which often proves impossible for weaker students.

There is some skill involved in choosing the hints for multiple-choice questions. These need not indicate exactly what is wrong with a particular answer choice, but often just ask the student a further question, or suggest a line of thought, as in Figure 4. This has been done to avoid excessive spoon-feeding.

Diagrams and graphs can be included in a question, as in Figure 5. These can be created at the time a particular version of the quiz is being generated, and so can use the actual random parameters for the question to which they refer.

The level of interaction with the server is customisable. Quizzes may be generated which do not contact the server at all. These are suitable for compiling collections of quizzes on CD. For use as a compulsory assessment task, quizzes can be personalised for each student. All interaction, such as access times, requests for quizzes, quiz submissions and times taken for perfect scores are recorded on the server. When recording quiz scores, the answer choices are also logged, so that a profile of a student's pattern of success or failure can

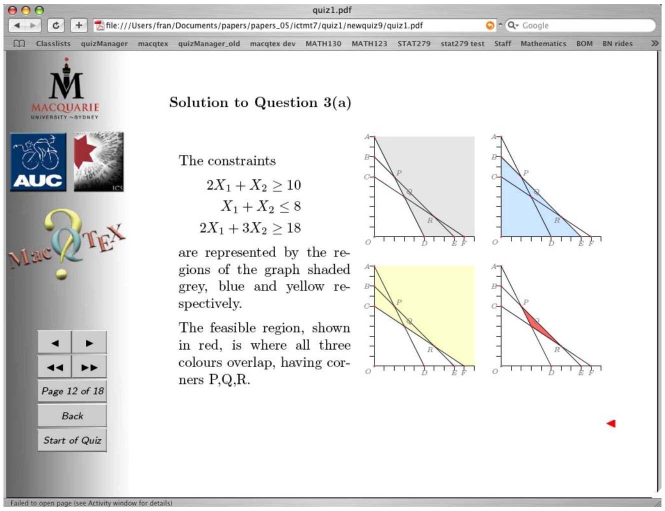

Fig. 5. A solution showing dynamically created graphics, based on the numeric parameters used in this instance of the question.

be built up, thus allowing staff to further advise the student if necessary.

B. *Quiz management tools*

The MacQTEX quiz project includes an extensive set of quiz and class management tools. These are available through a simple web interface. Each student can view his/her personal quiz log as a web page. This shows pass status and best score for each quiz, access details, scores and answer choices for every attempt at each quiz, times taken for perfect scores, and records of access being denied or reinstated.

Number of students enrolled: 321.

	quiz1	quiz2	quiz3	quiz4	quiz5
Total attempts (submissions)	660	613	1406	1019	1004
Successful attempts	517	460	435	380	349
Students who attempted (downloads)	313	311	310	302	293
Students who passed	310	309	293	286	271
Average attempts	2.11	1.97	4.55	3.41	3.48
Maximum attempts	97	16	20	21	23

Fig. 6. Statistics of quiz activity. Quiz 1 and Quiz 2 were on assumed knowledge, the remaining quizzes on new material. This shows the increase in total and average attempts for Quizzes 3, 4 and 5.

Class statistics are available in both numeric and graphic form. Numeric displays include numbers of downloads, submissions and successful attempts. An example is shown in Figure 6. These counts represent both total activity and numbers of individual students who are active. Average and maximum numbers of attempts are also included. Graphic displays, such as those shown in Figure 7 and Figure 8, of usage patterns include overall usage, daily and hourly averages, overall activity for each quiz and numbers of incorrect responses for each question. These graphs are generated on the fly using the Unix GDGraph utility [10]. The numeric statistics can easily be included on a class web site, dynamically updating each time the page is loaded. The intention is that students are more likely to participate if they see that the majority of their peers are doing so.

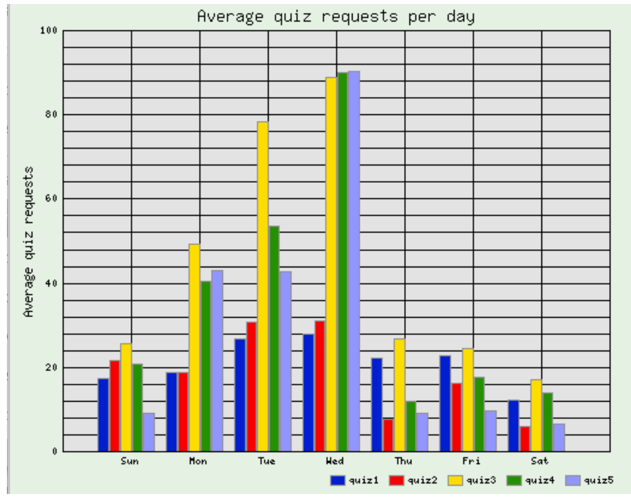

Fig. 7. A graph of daily quiz usage. The high usage on Wednesdays results from that being the day on which the quizzes were due each week.

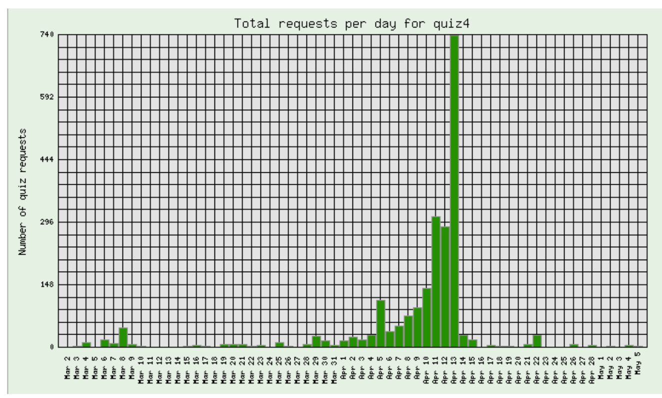

Fig. 8. Daily activity for a single quiz. Guess which day the quiz was due!

Similarly, lists of Student Ids of those who have not fulfilled quiz requirements can be posted and dynamically updated on the class web site. This is usually displayed in a prominent position, such as an assignment download page, late in semester, to chase up those students who are no longer bothering to attend lectures and have 'forgotten' about the quizzes. Recalcitrants are also sometimes contacted individually, reminded of the consequences of not completing the quizzes, and encouraged seek help if needed.

In fact, the Mathematics Department has set up a system which requires students to download personalised (but not randomised) copies of their written assignments. When a student requests his/her assignment, this system asks MacQTEX for the student's quiz status. If a quiz deadline is coming up and the student has not yet passed, a reminder is provided. If a deadline has been missed, the student is reminded of the consequences of failure to complete the quizzes. Students who have missed quiz deadlines can have their access reinstated for an arbitrary length of time.

Pass marks for quizzes can be chosen, otherwise the default is full marks for a pass. Generally one or two errors are allowed, since students may mistype an answer to a fill-in question, and still have a chance of passing the quiz. It is not uncommon for students to type a syntactically correct answer, but one that does not quite correspond to the notation they have written down when solving the question. The syntax used in such fill-in questions is similar to that of many traditional programming languages and spreadsheet formulæ. Whilst quite abstract, rather than trying to simplify this to become more flexible, it is generally felt that students need to develop the skill of being precise in their mathematical language quite early in their university careers.

In addition, the messages presented to students at various times during quiz interaction are customised. These messages can direct the student to a particular staff member or on-campus service, depending on the outcome of the quiz, or if the student has missed a deadline.

C. Production of quizzes

Macquarie's Department of Mathematics has traditionally been Mac and Unix based, so it was natural to implement MacQTEX on Mac OS X. The choice of Unix also facilitated the commitment to open source software.

Mathematical typesetting always poses difficulties, particularly in an online environment. The rendering of mathematical notation in standard web pages is generally unsafisfactory and requires a great deal of painstaking design work. The TEX typesetting engine, and it variants such as LATEX [8] and pdfTEX [7], are commonly used by mathematicians, and produce the best possible presentation of mathematical notation. Fortunately these are fully programmable and web enabled, and so provide a flexible basis for creating high quality documents for use online.

PDF was a logical choice for preservation of layout, excellent mathematics typesetting and JavaScript interactivity. When the project began in 2001, the AcroTEX [9] package by D.P. Story had recently been released. This offered PDF forms functionality and the basic question types needed for a quiz. AcroTEX, and its later versions, have been heavily customised for use in MacQTEX and provide the basis for the LATEX [8] processing, via pdf-TeX [7].

The AcroTEX [9] package by D.P. Story is a large TEX package which provides a way of including interactive form fields, similar to those found on web pages, in PDF documents. These form fields are controlled by JavaScript [6], just as they would be on a web page. Many customisations and extensions have been made to AcroTEX in order to provide the appropriate functionality for MacQTEX.

Colour and navigation has been added, using the `pdfscreen`[11] package by C.V. Radhakrishnan[2]. Graphs can be generated on the fly using the TEX graphing packages PSTricks [12] and PDFTricks [13].

All back-end processing is done using Perl and MySQL, as is the randomisation. The use of computer algebra packages, such as *Maple* or *Mathematica*, is not necessary, as most of the processing for which these would normally be used is done client-side in JavaScript.

The setting up of new quizzes is achieved using a web interface. A lecturer simply chooses the questions from a catalogue of existing questions, decides on the colour scheme and level of server interaction. A sample quiz is then automatically generated and presented for checking. There is no need to write LATEX code at any time. Once satisfied, the lecturer then confirms the quiz, and the first set of randomised quizzes is generated. When these are almost used up by the students, another set is automatically generated.

The final step in producing a quiz involves encrypting the PDF document so that students cannot view the contents of form fields, and hence the answers to the questions, using Acrobat Professional. This is achieved using the PDF encrypt tool in the Java application, Multivalent [14].

In principal, MacQTEX is suitable for any discipline in which specialised notation and typesetting are important, and where such typesetting is generally difficult to present effectively on standard web pages.

D. Question authoring

As with other quiz systems that randomise question parameters, the task of question authoring is more onerous than one would like. For MacQTEX quizzes, each question requires a LATEX source and a Perl source to be written. The LATEX source is a skeleton of the question, containing references to macros which act as place-holders for the random parameters. The Perl source generates the definitions of these macros.

Most of the programming effort is involved in writing the fully worked solutions. As these solutions are based on the actual random parameters used, all intermediate results must be generated. This means that the efficient library routines one might normally use are inadequate, since they produce only the final result of a calculation. Sacrificing efficiency in the generation of random parameters is not significant, as most of the processing time needed to generate a quiz instance is taken up by the typesetting, not the randomisation. Hence it is necessary either to alter an existing library routine to produce the appropriate output, or write it from scratch. The latter strategy is often necessary in order to reproduce the algorithms that students are being taught. These are suitable for hand calculation but not necessarily efficient from a computing point of view.

Random parameters must be chosen so that the tedium of any numerical calculations does not overwhelm the concept the question is intended to reinforce. For example, it is desirable to avoid fractions for as long as possible in matrix algebra. On

[2]pdfMacQTEX's implementation of `pdfscreen` predates that currently available in AcroTEX, and has not been changed.

the other hand, instances of a question being made trivial by unlucky parameter choice should be avoided. Once generated, mathematical expressions must be filtered so that fractions and surds are reduced to lowest terms, instances of silly notation such as $1x$ or x^0 are removed, and an appropriate level of factorisation is carried out. This is important as students should be encouraged to present their solutions using succinct and precise mathematical language.

Some of this attention to detail can be avoided for quizzes in statistics, as numeric answers are typically presented as decimals, rather than using exact notation such as fractions or surds. The tolerance of precision can be adjusted to allow students some lenience in the manner of rounding their decimal answers.

The amount of variety in the random parameters of a question is best determined by educational considerations rather than by the limitations of programming practicality. The former, in most cases, often leads to a simplification in the latter anyway. For example, it is possible to construct a question on differentiation of functions that includes all the usual special cases of the chain rule. In practice however, a lecturer will often teach these special cases separately. Thus it is more useful (and easier to program) several questions, each on a different case of the chain rule. Also, certain cases of a particular question may present greater difficulty to students than others. Hence the randomisation can be designed so that these cases occur more often, thus providing students with extra practice. For example, a question on solving systems of linear equations may present a multiple solution much more often than an inconsistent system. The unique solution may be better presented in a separate question however, as students learn this type of linear system first, and benefit from being able to practise the straightforward case before tackling the more difficult cases.

III. Online quizzes as a learning tool

A. *Quizzes for formative assessment*

When used for mathematics and statistics units at Macquarie University, it is usual to have one or two assumed knowledge quizzes due within the first three weeks of semester. Quizzes on new material are provided at appropriate intervals during the semester, to reinforce concepts and encourage students to practice the techniques that have just been presented in lectures.

A student can make multiple attempts to solve the problems, as the randomisation feature of the quizzes ensures that during each attempt, the student is presented with a different version of the problem. At the time of submission, the system provides students with instantaneous feedback on their performance and directs them to seek help if serious problems are identified. Seeing detailed solutions immediately encourages learning. It has also been observed that a student is more likely to try again within short time period if a detailed solution is provided, rather than if a more general solution is given. Students' scores have also been observed to improve rapidly from one attempt to the next.

The kind of question that is asked is generally of a quite routine nature. As such it is not of the kind that would normally be posed in a written assignment, where the students' deeper understanding and reasoning ability is being put to the test. Instead, the aim is to encourage (or even force) students to gain proficiency at solving routine questions. Without such proficiency in basic techniques it is much harder for them to learn to perform the more complicated techniques and algorithms that are the substance of the particular material being taught.

As an example, when students are introduced to complex numbers, a quiz would typically begin with several questions on the arithmetic of complex numbers. Next, students are asked to convert between cartesian and polar notation. The final questions, on powers and nth roots of complex numbers using de Moivre's theorem, build on the expertise gained in the earlier questions. In this way, students acquire the essential skills associated with the topic. Later, in a written assignment, they are asked questions that test their deeper understanding of the topic. These questions assume the general level of proficiency gained from the quiz. Because the quiz must be repeated until passed, this technical proficiency has been (at least temporarily) achieved by most students.

Since only the most conscientious student would choose to do work that is not assessed or has no marks allocated, it is necessary to provide students with sufficient incentive to actually do these quizzes. Experience shows that it is best to make the quizzes compulsory, but contributing very few or no marks towards a student's final grade. The lack of marks is due to the unfortunate reality that a significant number of students (indeed probably those who would benefit most from doing quizzes) would most likely 'collaborate' just a little bit too much. In practice, the weaker students typically repeat a quiz many times before attaining the Pass level. Thus these students gain an amount of practice that they would not otherwise be motivated to do. On the other hand, the more capable students might well find the task to be fairly minor; yet it is helpful in building their confidence with the relevant concepts.

As for administering the quizzes and enforcing deadlines, the mathematics and statistics staff at Macquarie is generally quite lenient. Students who miss deadlines are always given extra time to complete their quizzes, even when they are many weeks behind the advertised schedule. Deadlines can be set automatically so that a quiz must be at least attempted by a certain date, yet need not be completed successfully until a few days later. This gives a period of grace to those who fail to heed advice about starting work early. If either deadline is missed the student is denied access to the quiz. A message directs him/her to the relevant staff member, who will listen to the excuse before deciding to re-instate access. Once a quiz has been passed, it remains available to the student until after the end of semester exam period, allowing it to be used as a source of automatically marked revision exercises.

B. Identification of students who experience difficulties with subject matter

The timely identification of a student who is experiencing difficulties in a unit is challenging enough at the best of times, but it becomes even more difficult when the unit enrolments are very large. Students with insufficient background knowledge need to be identified early on in the semester and appropriate action needs to be taken in order to help these students along. Furthermore, students that start to struggle with the unit subject matter or fall behind during the semester need to be identified as soon as possible and assisted.

A minimum time delay between students doing the assessment task and the feedback from teaching staff is of great importance when identifying students with insufficient background knowledge. In the past, written assessments such as assignments or class tests, given out early in the semester, were the only means used to identify these students. This practice works very well when the classes are small and feedback to students can be done soon after students have completed the assessment task, but it becomes quite impractical when large student numbers are involved. The increased number of staff and the amount of time needed to mark the written assessments in order to provide timely feedback to the students is simply not available, so an automated system, such as MacQTEX, may be the best solution.

At the beginning of the semester, students are invited to solve a selection of assumed knowledge problems. These problems have been selected to give an indication of whether the student has the required background knowledge and technical skill to provide sufficient foundation for the unit subject matter throughout the semester. The assumed knowledge quiz is not intended to be an assessment tool as such, rather it is designed to identify students that might otherwise fall through the cracks and not be able to cope with the unit material due to insufficient background knowledge. It is also designed to encourage self learning. In most of the units that use the MacQTEX system, the assumed knowledge quiz does not carry any weight towards the final assessment, though it is a compulsory part of the student workload.

The system also can identify students that are taking an unduly long time or who need an unreasonable number of attempts to solve and pass routine problems, as well as students who are not participating at all. It can highlight overall difficulties, as well as difficulties with individual topics within a quiz. After identifying which students are experiencing greater than expected difficulty, appropriate action can be taken. Contacting the relevant students via e-mail is normally the first step. During this process students are encouraged to seek help either from the teaching staff involved in the relevant unit or from a help centre for mathematics and statistics students. Such a help centre operates within the University and provides extra tuition both on an individual basis and to groups. Not all students require the same level of assistance; some require extra tutoring while for others providing them with a list of further reading material is sufficient to gain a reasonable level of background knowledge to successfully complete the unit.

Similar methods and actions apply to identifying and helping students that start to struggle or fall behind during the semester, by using quizzes based on material directly from the topics of the unit. It is desirable that students develop a certain level of independence and resourcefulness, and learn how to find relevant information in their own lecture notes and text books.

C. Determining students' level of understanding of a particular topic

Written assessments have been commonly used to identify topics within the unit subject matter that are causing difficulties for students. As seen before, lecturers running units with a large number of students may find this impractical. Large units often involve many markers where variation in marking, as well as a lack of overview can make it very difficult to accurately identify such topics. Time is often a problem here as well; an unduly long time often elapses after students complete the assessment before any reliable statistics on student performance is available. Again, MacQTEX can be used to assist in this matter.

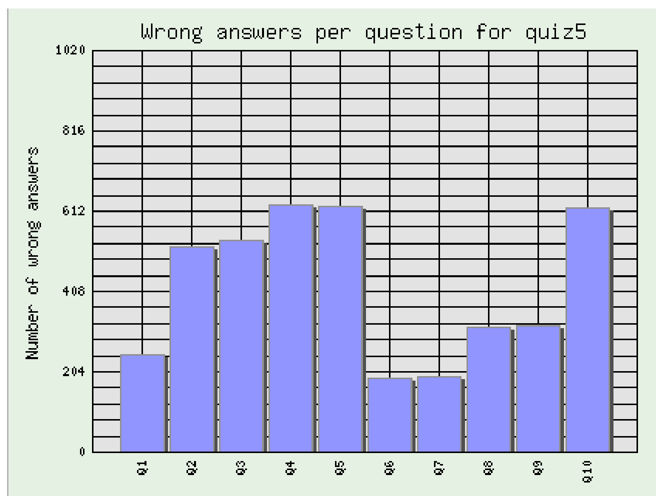

Fig. 9. Numbers of wrong answers for each question. It is clear that questions 6 and 7 were easy, but students had considerable difficulty with questions 4, 5 and 10.

MacQTEX provides graphs that enables the lecturer to see immediately whether an individual topic is problematic for students. In Figure 9, we observe that a considerable number of students are getting questions 4, 5 and 10 wrong but are having less difficulty with the other questions. After ensuring that it is not the question itself or the programming that is at fault, actions can be taken in order to clarify the subject matter for the students. This clarification of the subject matter can be implemented during lectures, tutorials or by using electronic bulletin boards. In order to assess whether the lecturers' intervention was successful, follow up questions on the same topic can be introduced into a quiz later on in the semester. These would also reinforce students' understanding of the topic.

Of greatest advantage when using such a system is that very little time elapses between the completion of the task by students and the analysis of students results by the teaching staff. Actions to rectify students difficulties can be implemented almost immediately. The lecture material can also be adjusted to incorporate any clarification on any challenging topics that have been identified for future offering of the unit.

D. Positive effects on students' learning behaviour

A considerable difference has been noticed in the learning behaviour of students that at some stage during the semester are flagged as being in need of help and have been contacted by the lecturing staff and offered assistance. Since students with insufficient background knowledge are identified very early on in the semester and appropriate action taken in order to rectify the situation, students get the sense that their lecturer cares that they succeed. What has been noticed is that those students tend to start subsequent quizzes and other assessment tasks earlier than they used to, and seek help more freely. When asked, most of those students admit that they would never have sought help unless they had been invited to do so. Furthermore, an overall announcement during a lecture or a tutorial would not have prompted a considerable number of those students to seek help.

In general, students like the fact that the quizzes are intended to be a learning tool for them, rather than simply being yet another assessment tool. In fact, in one second year mathematics unit, students indicated their disappointment that the unit had no quizzes! Students have commented very positively on the unlimited number of attempts they can have at solving the quizzes as well as the full solution that is provided after submission has taken place. When asked, all students say they learned a lot about critical thinking, problem solving techniques and the subject matter generally, from looking through the fully worked solutions. Furthermore, students like the diversity in question types; multiple choice, multiple response and fill in answer. Some students initially experience difficulty in correctly typing the syntax for mathematical expressions. On seeking help however, this often reflects a faulty understanding of the conventions of mathematical notation in general, such as order of operations and use of parentheses.

One feature has been added for the benefit of the more capable students. When full marks have been attained for a quiz, the time taken to do that quiz is revealed. The student is then invited to enter his/her nickname in the Champions List, similar to what is done in many computer games. Some students enjoy the challenge of bettering their times, and have posted some amazingly fast times (better than most of the teaching staff could do!). This explains the 97 attempts at Quiz 1 in Figure 6, which was made by one of three students competing for the fastest time.

IV. Conclusion and future development

It is always difficult to quantify the effects of the introduction of a new teaching inniative. Successive cohorts cannot always be compared, due to differences in average ability or experience. In particular, the mathematics units at Macquarie have had quite variable cohorts for several years. This has resulted from the restructuring of degrees outside the Mathematics Department, which has affected student numbers, and the time at which students undertake particular units. Finally, the Mathematics Department itself, has recently restructured its own first year units.

Anecdotal evidence from staff involved in the marking of examinations strongly suggests a positive effect on student grades. In particular, the proficiency with use of mathematical language and students' ability to express mathematics coherently has improved. In statistics units, there has been an observed improvement in students' attempts at routine questions. There has also been a positive effect on the way students tackle the more involved problems, in that they have a better appreciation of how to break the problem down into a sequence of tasks.

The use of online quizzes will be extended further in the first and second year mathematics units, as well as more statistics units at third year level.

Partial automation of question authoring is highly desirable. So far no work has been done on this for MacQTEX.

At present, the processing of fill-in questions is done by simply comparing the students and authors answers, evaluated at several randomly chosen points. Some pre-processing is done to check for syntax errors and illegal notation, such as decimals, if disallowed. The student is alerted to fix any errors of this type before the answer is evaluated. A more sophisticated method of evaluation may lead to the ability to provide reasonably helpful feedback for incorrect answers.

The MacQTEX quizzes are available for public access online at http://www.mq.edu.au/quizzes. Any quiz is accessible by entering guest as your Student Id. Acrobat Reader 5.0 or later is required. An installer for Mac OS X is also available on http://sommelier.ics.mq.edu.au/ MacQTEXabout/downloads.html.

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