

Embedding Intelligent Web Based Assessment in a Mathematical Learning Environment

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Abstract

In this paper, a case is made for linking a Computer Algebra System into Computer Aided Assessment systems. It is argued that such a link will significantly reduce the restrictions that CAA packages otherwise impose on educators. A CAA package based on a CAS, i.e. AIM, is used to illustrate the advantages and the possibilities that emerge from more intelligent CAS. A variety of uses within a learning environment are discussed. These rely crucially on accessibility over the internet, which helps to promote student centered learning scenario's.

1 Introduction

The full potential of the internet for learning and teaching in Mathematics has not been attained for a number of reasons. The display of mathematics on the web was undoubtedly the most crucial one. But another important hurdle was the fact that, for a long time, commercial computer aided assessment packages featured serious restrictions when applied to questions in mathematics. Many educators do not like to use only multiple choice questions or other “objective tests”. But the alternative, i.e. allowing the user to enter any mathematical expression as an answer, poses significant practical difficulties. A common syntax is needed, which should be easy to learn and use by students early on in their studies. The answer provided needs to be checked and analysed in an intelligent way. For example, integrating an expression can lead to two quite different, but correct expressions. Both should be recognised. Even wrong answers may contain features that show a level of understanding and deserve a partial mark. One solution to these problems is to link a computer aided assessment package to a computer algebra package. Recently, several packages have emerged and more are being developed. Examples include Calmaeth [10], which uses Mathematica, and AIM [1, 6], which builds upon Maple ¹.

¹Maple is used as a collective term for MapleV ©, Maple 6 © or later versions.

At The University of Birmingham, we have been using AIM to provide a databank of questions which are delivered over the web and are assessed by the computer. The link with Maple brings to computer aided assessment many extra features. It provides one solution to the practical questions posed above. It yields the possibility of setting generic questions where not just parameters but also functional arguments can be randomised. It enables a thorough analysis of the answer to reveal particular features and to provide tailored marks and feedback.

In this paper, I will try to summarise the need for “intelligent” CAA, i.e., CAA linked to a Computer Algebra System. I will then briefly describe one such a system, i.e. AIM. Through a series of examples, the impact of the link with a computer algebra system will be illustrated, followed by a brief discussion of the various contexts in which CAA systems like AIM can be used and how it can be integrated into a learning environment.

2 The need for Intelligent Computer Aided Assessment

In the U.K., the expansion of student numbers in Higher Education has given further impetus to the use of computer aided assessment. With large classes, the rapid turn-over in marks and feedback that computer based systems can provide, combined with the consistency in marking, has made the initial investment in moving to such systems more acceptable.

The emergence of the web, combined with improved access to computers for students, both on campus and at home, is stimulating the provision of web-based systems, that can be linked to from a variety of sources, including virtual learning environments (VLE's).

There are several issues that need to be addressed when using computer aided assessment in mathematics. Consider the following question:

Question 1: Determine the following integral:

$$\int \cos(x) \sin(2x) dx.$$

The simplest approach is a multiple choice question, with, e.g., the following set of possible answers:

- $(2/3) \cos^3(x) + C$
- $-(2/3) \cos(x) + (2/3) \sin^3(x) + C$
- $-(2/3) \cos(x) + (1/3) \sin(x) \sin(2x) + C$
- Don't know.*

But do we really ensure the student actually completes the integration? The answer can be identified by checking which of the possible answers, when differentiated, match the integrand. This is a striking example of how the adaption of a paper based question for use with a CAA package can affect the learning outcomes one is expecting to test (See also [2]). The change in tested learning outcomes following the adaption of a question to a CAA format can be far more subtle than this. For example, McGuire et al. ([3]) have studied the effect a mere rewording of questions has on student performance.

Coming back to the question presented above, the obvious alternative is to expect the students to type in the expression of the integral. This immediately raises the issue of syntax.

In AIM, this is resolved by using the Maple syntax. At Birmingham, students will be exposed to Maple early on in the first year, so that they should quickly become familiar with the syntax. It is also important to consider the problems students might have with entering expressions. Simple typographical errors or syntax errors should ideally be checked for prior to validating the expression, so that corrective action can be taken without penalising the student.

The other issue is the validation of the entered expression. Both $-(2/3)\cos^3(x)$ and $-(2/3)\cos(x) + (1/3)\sin(x)\sin(2x)$ are correct answers, but they constitute different expressions. The use of a Computer Algebra System in the validation of such answers is the obvious solution.

Not only can a CAS check the equivalence, it can also validate the answer by checking its properties. For example, consider one asks for the root of a given function, $f(x)$. The student gives a value, a , and the correct answer is b . Instead of checking whether $a = b$, one can verify that $f(a) = 0$. This then allows for questions with multiple answers. Previously, educators often had to rephrase this question as “Give the largest root of $f(x)$ ”, to ensure the uniqueness of the answer. So again, restrictions on possible question types are eased.

This is also illustrated in the following question:

Question 2: Determine the solution of the differential equation:

$$\frac{d^2y}{dx^2} + 2\frac{dy}{dx} - 5y = e^x,$$

when $y(0) = 1$ and $y(1) = 0$.

Here, a CAS system would not only be able to check the answer by substitution into the given differential equation and verification of the boundary conditions, it could also be used to award partial marks, e.g., for the correct format of the solution or the correct implementation of the boundary conditions even if the overall expression is incorrect.

Beside the partial marking referred to above, there is also scope for questions to be broken down in smaller steps at the request of the student, or the possibility to select hints (perhaps at a penalty). The performance on one question might be able to affect which question will be presented next. In all these, an underlying CAS would be extremely helpful.

Another area over which lecturing staff may wish to exercise more control is the timing and the extent of the feedback that is given to students. This can vary from a correct/false approach to the extreme of presenting a fully worked out solution with annotation. A variety of learning environments may need a variety of feedback provision. But crucial in all this is the speed with which this feedback is available to students. The immediate feedback that CAA can provide helps to keep the student engaged with the material and can provide further encouragement to continue with the activity.

Where the first commercial CAA packages tended to restrict the teacher, intelligent CAA, accessible over the internet, can allow the educator to mould questions, marking and feedback to fit stated objectives to a much larger extent.

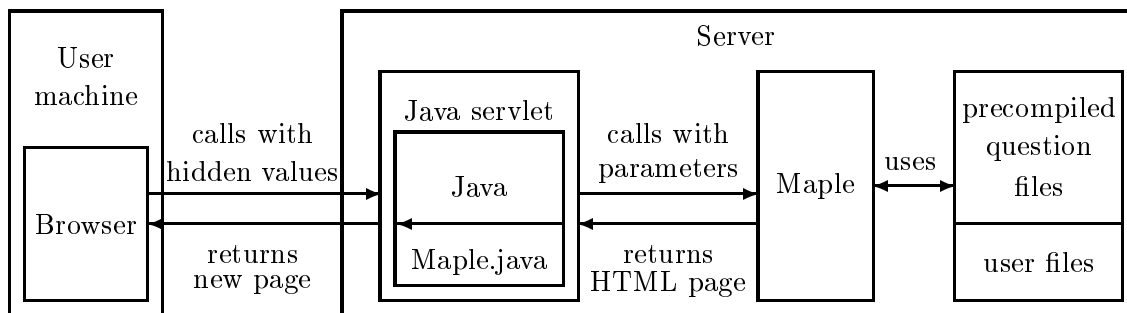


Figure 1: Overview of AIM.

3 The AIM System

3.1 Overview

The AIM (Alice Interactive Mathematics, [1]) system was developed from the ALICE Project at the University of Ghent, Belgium. The ALICE project had developed a quiz provision coded in Maple to supplement on-line notes with tutorial questions. AIM then provided a Web interface and teacher facilities.

AIM is mainly programmed in Maple, with Java and a Java servlet taking care of the communication between Maple and HTML. AIM is an open source project. It requires, besides the Maple source code, the Java Runtime Environment (JRE), which can also be freely downloaded and of course a version of Maple itself, release 5 or above. For installation instructions, see [7]. The user only needs access to a standard browser and does not need to have a copy of Maple on the local machine. This makes AIM widely accessible. Figure 1, taken from [5], gives an overview of how the various subparts of AIM interact.

Output to the screen is via HTML pages, using either HTML syntax or a conversion of Maple output to HTML.

3.2 Questions and quizzes

The question files are simple text files, which can either be edited via the web interface, or edited using any text editor and imported prior to compiling. AIM uses a combination of flags and HTML syntax. A simple example of a questions file is given below:

```

h> a:=rand(5..7)();
t> Calculate  $3^2 - a$ .
h> sol:=3^2-a;
a> sol
end>
  
```

The "h" flag allows for Maple definitions or calculations which are hidden from the user. In this case, the variable **a** is given a random number between five and seven using the Maple

rand() command. The "**t>**" flag displays the text of the question, where the "**\$a**" notation allows for the value of the Maple variable to be printed. The "**a>**" flag provides the correct answer. Also notice the HTML tags used to print the power. A full description of flags can be found at [8]. More flags will be introduced later in this paper.

The question files are compiled into a database of questions from which one can then assemble a quiz. A quiz is the test as presented to the student. The web interface allows for questions for a new quiz to be selected from a list. Alternatively, a Maple procedure can be used to select (randomly) certain questions or to select questions in a different order. Keywords can be set in the question files, using a "**k>**" flag and can be used to select questions into a quiz.

AIM will add any new quiz to a list of quizzes for a particular course, but a different lay-out can easily be achieved by editing your own HTML page for the course.

3.3 Teacher's interface

AIM generates an HTML page which lists the courses created and allows teachers to

- edit/create or delete questions,
- edit/create or delete quizzes,
- edit an initialisation file,
- view the log file of student responses,
- produce grade reports and other statistics,
- access student information.

This web based interface for teachers allows them to do most activities from any computer with internet access, except for adding a course or moving question files into a directory on the server, which require access to server directories.

A particular useful feature is the log file of student responses. This logs every submission from the quiz page to the system and contains, besides all the answers, further data on time and location from which the submission is made. Having access to students answers is extremely helpful when, e.g., a question turns out to be ambiguous and a possible acceptable solution has not been catered for. There is no facility yet built in to convert the log file to specific formats, but this can be easily be done using, e.g., a perl script. An example of such a facility can be found in [5]

Each course has a teacher's password which provides access to the administrative functions. Students are registered in a course using a userid, and need to provide a password at their first point of access. They will need to specify these everytime they open a quiz. For practice purposes, guest access can be allowed.

3.4 Question types

Several question types are provided, which include some generic one. The flag "c>" allows the teacher to specify the question type in the question files. Currently, the following types are provided (for details see [8]):

- unspecified, any valid Maple expression will be accepted as an answer,
- multiple choice,
- multiple response, full marks are only obtained if all answers are provided, marks are deducted if additional wrong options are selected,
- matrix, the answer is a matrix of given size, an element by element comparison is performed,
- list, the answer is a Maple list, given as $[\dots, \dots, \dots]$, where an element by element comparison is performed,
- string, the answer is a Maple string, and a string comparison is performed,
- constant, allows for approximate numeric answer
- any specified Maple type, answer has to be of the given type.

There are a few more string options which allow the number of input lines or custom HTML tags for the input box to be specified. These are useful for more lengthy textual answers, like comments on a questionnaire.

AIM will flag up to the user any mismatches in type or indeed some readily recognisable typos, and allow the student to correct these without loss of marks. The ability to enter valid Maple expressions does pose the problem that students might avoid a calculation by hand by typing the relevant Maple command, e.g. "int(x^2, x=0..3)". This can be addressed by the "forbid>" flag which allows the teacher to specify key strings that should not be found in the answer.

3.5 AIM-TTH

Recently, N. Strickland at Sheffield University has provided a further developed version of AIM which uses the tth (tex to html) converter [11] to allow more professional mathematical presentation in the question presentation. The tth converter translates tex into html, primarily using tables, and produces reasonable results for not too complex mathematical expressions. The AIM-TTH version also adds some functionality to test delivery and administration. Information on this version can be found at [9].

4 Exciting possibilities

The ability to use a CAS in the question setup as well as the evaluation of the answer opens up a number of exciting possibilities for the teacher. In this section will give a small number of

examples to illustrate what can be achieved and how these added features can impact on the learning environment.

4.1 Example 1

Consider the following question

Consider the flow chart handed out at the beginning of this test. Give the first six numbers which this procedure will print out.

The flow chart illustrates a procedure which will print out a sequence of numbers. Students are asked to read the flow chart and predict which numbers will be printed out. This question featured in a class test of a level 3 FORTRAN Programming course.

When marking this question, the teacher was prepared to give marks for every correct value, even if not all of the six values were correct.

This question can be generated in AIM using the following question file:

```
t> Consider the flow chart handed out at the beginning of this test.
t> Give the first six numbers which this procedure will print out.
c> [constant, constant, constant, constant,constant,constant]
h> sol_:= [2,1,3,10,5,16]
v> 3
s> [proc(chk,s1) \
    local co_; \
    co_ := chk-s1:
    if co_ = [0,0,0,0,0,0] then\
        1;\
    elif co_[1]=0 and co_[2]=0 and co_[3]=0 and co_[4]=0 and co_[5]=0 then\
        2./3;\
    elif co_[1]=0 and co_[2]=0 and co_[3]=0 and co_[4]=0 then\
        2./3;\
    elif co_[1]=0 and co_[2]=0 and co_[3]=0 then\
        1./3;\
    elif co_[1]=0 and co_[2]=0 then\
        1./3;\
    else \
        0.;\
    fi;\
end, sol_]
sb>
t> (Partial marks have been given.)
se>
end>
```

The "v>" flag indicates the maximum amount of marks (default is 1). The "s>" flag allows the teacher to specify a Maple procedure of a given format which will return a mark between



Figure 2: The question in Example 1 before and after an answer is entered.

0 and 1. The first argument is the student's answer, the second the correct solution to be displayed. The "**sb>**" and "**se>**" flags enclose feedback which the teacher wants to display after the question has been marked. The flow chart referred to in this question was provided on paper at the start of the test, mainly because it was deemed easier to work with than having it displayed as part of the question (which can be done).

The Maple procedure will calculate the difference between the values in the list provided by the student and the values in the correct sequence. Hence, for a correct answer, the maple variable `co_` will be a list of six zero's. A simple IF-THEN-ELSE construction allows to award reduced marks for an initial sequence of zero values. In Maple, `co_[2]` refers to the second element in the list `co_`.

Figure 2 gives a view of the question as presented to the students as well as the screen presented after the student has marked the question. Notice that the student can take two actions. **Validate** allows the student to verify and mark his answer without revealing the correct solution. In this example, the quiz is set-up to allow the student to retry the question if an initial attempt is incorrect. A 15% (cumulative) penalty is applied at each further attempt. Using the **Validate** button will only inform the students whether the answer is correct or incorrect.

The **Validate and show solution** button will produce further feedback. In this case, the teacher's answer is produced, as well as the comment written in the question file after the "**sb>**" flag. When students have a deadline set, the **Validate and show solution** button will only be available after the deadline. AIM allows for the labels on the buttons, or indeed most other generated responses, to be changed by the teacher. For example, **Validate** can easily be changed to **Mark**.

The possibility to use a Maple procedure for marking the student's answer opens a whole gamma of possibilities. In this case, a rather straightforward construction is used to award partial marks for partially correct answers. But one can build into this procedure a more intelligent analysis of the answer. The limits of such an analysis are determined by what one can do in Maple.

4.2 Example 2

Consider the following question, taken from [4]:

Give an example of a differentiable function $f(x)$ which has a turning point at $x = 1$.

Questions like this are often avoided by teachers because they have multiple correct answers. Marking such answers then requires that all specified properties are satisfied, which by hand often constitutes an onerous task. In this case, if the student returns $g(x)$ as the answer, the teacher needs to verify that $g'(1) = 0$.

The following question file is used to generate this question in AIM:

```
t> Give an example of a differentiable function
t> <i>f(x)</i> which has a turning point at <i>x=1</i>.
v> 2
ap> <i>f(x)=</i>
s> [(ans)->'aim/Testzero'(subs(x=1,diff(ans,x))),x^2 - 2*x+3]
end>
```

Here, the flag "ap>" allows the teacher to specify the prompt for the answer box. A slightly different format is used for the procedure which marks the answer. The procedure uses the function `aim/Testzero()` which is a slightly modified version of the maple function `Testzero()` which checks whether the given argument is zero. The derivative of the expression given by the student as the answer is calculated using the command `diff(ans,x)`. The Maple `subs()` command is then used to substitute the value $x = 1$ into the derivative. If this evaluates to zero, `aim/Testzero()` will return full marks (1 by default). The second argument in the list following the "s>" flag is the teacher's solution which, in this case, is not unique.

The ability to pose questions like this opens exciting new opportunities. It is argued that testing verification of a property is pedagogically different from testing the creation of an example, which requires insight and understanding rather than mere knowledge of definitions and algorithms (see also [4] and references therein).

4.3 Example 3

Another question taken from [4] is as follows:

Give an example of a cubic polynomial $p(x)$ with the following properties

- $p(0) = 1$,
- $p(x) = 0$ for $x = 2$ and $x = 3$.

This, again, is an example of a creative question with multiple solutions. Indeed,

$$p(x) = \left(1 - \frac{x}{2}\right) \left(1 - \frac{x}{3}\right) \left(1 - \frac{x}{\alpha}\right),$$

for any value of α will satisfy these conditions.

Again, AIM enables us to create this question and automate the marking. But in addition, we can randomize the values at which the roots are located. In the implementation below, the

first root is at a value p_* which is a random number between 1 and 3. The second root is at a value found by adding 1 or 2 (randomly chosen) to the value of the first root. This is achieved by using the following question file:

```

h> p_:=rand(1..3)();
h> q_:=p_+rand(1..2)();
t> Give an example of a cubic polynomial  $p(x)$ 
t> with the following properties
t> 


t> - $p(0)=1$

t> - $p(x)=0$  at  $x=p_*$  and  $x=q_*$


v> 4
ap>  $p(x)=$ 
s> [proc(ans) local marks_; marks_:= 1;\
    if not 'aim/Testzero'(subs(x=0,ans)-1) then \
        printf('Your polynomial fails to satisfy  $p(0)=1$ .<br>');\
        marks_ := marks_ - 0.25; \
    fi;\
    if not 'aim/Testzero'(subs(x=p_,ans)) then \
        printf('Your polynomial fails to satisfy  $p(x)=0$  at \
         $x=%g$ .<br>',p_);\
        marks_ := marks_ - 0.25; \
    fi;\
    if not 'aim/Testzero'(subs(x=q_,ans)) then \
        printf('Your polynomial fails to satisfy  $p(x)=0$  at \
         $x=%g$ .<br>',q_);\
        marks_ := marks_ - 0.25; \
    fi;\
    if not 'aim/Testzero'(degree(ans,x)-3) then \
        printf('Your polynomial is not a cubic.<br>');\
        marks_ := marks_ - 0.25; \
    fi;\
    marks_;\
    end,(1-x/p_)*(1-x/q_)*(1-x)]
end>

```

In Figure 3, the question is shown as presented to the student, as well as the feedback obtained after the first attempt. Here, the Maple procedure is not only used to mark the answer, but is also serves to provide accurate feedback on where the answer is wrong. The ability to analyse the answer in more detail and provide individual feedback brings the interactive process between student and CAA much closer to the one to one interaction a student may have with a tutor. This, again, allows CAA to be used in a pedagogically more considered way.

4.4 Example 4

From the AIM documentation at [8], we pick the following question:



Figure 3: The question in Example 3 before and after an answer is entered.

Evaluate the following integral:

$$\int \sin(2x) \exp(-x) dx.$$

Again, we may wish to randomize the integrand. In Maple it is possible to combine a given number of elements from a list using the `combinat[randcomb]()` command. This will generate a list of the required elements which can be converted into a product using the `'*(op())` construct. So, the Maple command sequence

```
'*(op(combinat[randcomb]([exp(-x),sin(2*x), cos(3*x)], 2)))
```

generates a random product of two out of the three terms given in the list. This is used in the following AIM question file:

```
h> f_:= '*'(op(combinat[randcomb]([exp(-x),sin(2*x), cos(3*x)], 2)))
t> Evaluate the following integral:
p> Int(f_, x)
a> (ans) -> 'aim/Testzero'(diff(ans, x) - f_), int(f_,x)
sq> penalty = 0.2
t> Use integration by parts.
end>
```

The flag "p>" is used to print a mathematical expression to the screen (via Maple). Again, `aim/Testzero()` is used, not to check the answer against a given correct solution, but to check that the answer satisfies the necessary properties. In this example, the derivative of the answer should be equivalent to the integrand of the given integral.

The flag "sq>" allows for a subquestion or hint to be provided. In this case, a penalty of 20% is incurred if the student selects the hint before answering the question. Here, the hint merely suggest that the student tries to apply integration by parts, but one can also present the student with a simpler subquestion, in which case the marks for this step need to be specified as well.

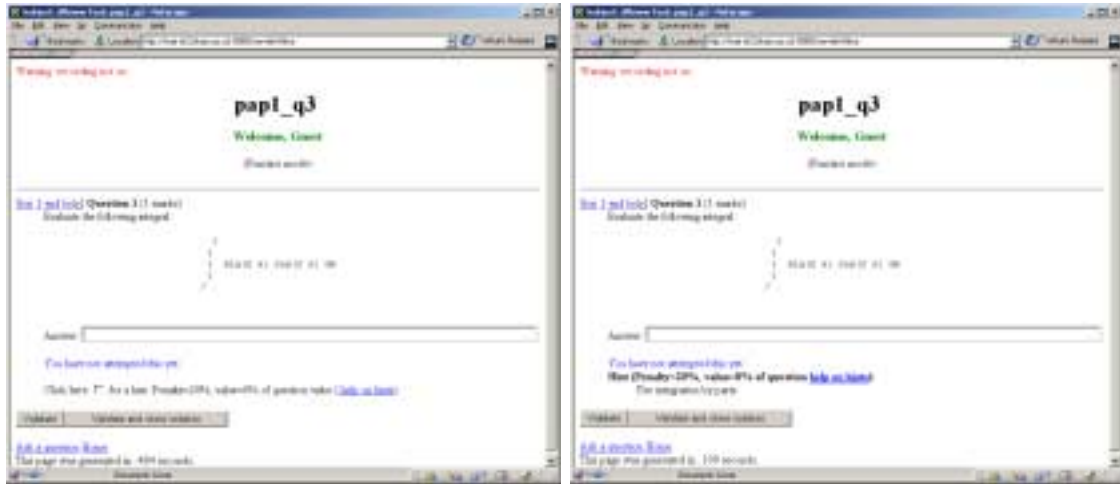


Figure 4: The question in Example 4 before and after the hint is selected.

Figure 4 displays the effect of selecting the hint. Notice that in this case, the hint has zero value, since it is not a task in its own right.

With this facility, students can be taken step by step through a question, whilst still maintaining a strong incentive not to use the hints or subquestions. Again, this helps the educator to design suitable suites of questions/quizzes for pedagogically different contexts.

5 Using AIM in a variety of contexts

Often, CAA packages or applications have developed with a particular learning context in mind. Packages like AIM allow teachers to exploit their usefulness across a range of situations. In this section, a range of contexts in which AIM either has been used at The University of Birmingham or is planned to be used, are discussed, together with some features that need to be catered for.

5.1 Continuous assessment

Here students are set exercises to do by a given deadline. They can return to a test several times. They may have several attempts at answering the same question, with each failed attempt carrying a prescribed penalty. Students can take these tests at any time or any place with internet access and feedback is provided immediately after the deadline has passed.

The possibility to recover from a failed attempt provides further encouragement for students to try and learn from their mistakes. The randomisation of parameters in AIM is such that the same test will use the same parameters for a given student, making it possible to, e.g. print out the quiz and solve it away from the computer. There is an element of concern that students cheat on paper based continuous assessment exercises by merely copying the answer from a friend. With these exercises made available via AIM, mere copying of results is excluded. Students need at least to perform an analogue operation on their own data, which forces them to engage more with the question than they might have wished to do otherwise.

AIM is particularly suited to operate in this way.

5.2 Self-assessment

In this context, marks are not the most crucial issue. They may be used to measure a student's effort in a course and as such contribute in a modest way to a final mark. More important in this context is the nature of the feedback provided. Different teachers have different views on what level of feedback stimulates learning most. AIM can provide a wide range of feedback, from a "right" or "wrong" response, via specific feedback supported by an analysis of the result to the blanket provision of the various steps in the solution. More research is needed to identify what feedback is more efficient in stimulating learning or more efficient in motivating the student to persist with self-assessment.

The ability to randomize parameters in questions or the selection of questions in a quiz allows a relatively small sample of generic questions to cater for a wide variety of quizzes. Students may be requested to log in so that each access to a test is monitored. If this is not deemed necessary, they may enter as *guests*. Following the approach by authors of calmaeth (see [10]), one question quizzes can be generated and integrated with other web based provision. Internet access to these quizzes is paramount to exploit the benefits of this student centered activity.

5.3 Classtest or exam

In this case, a group of students is set a CAA test in a computer lab under strict invigilation. The ability to randomize parameters means that two adjacent students are unlikely to have the exactly the same question and hence the possibility that one can look at each others display does not pose a serious threat to the integrity of the test. The invigilator must be able to close the quiz for any use at the end of the session, which, to allow for late starts or other unforeseen circumstances, may best be done manually from a computer in the lab itself. Students may or may not be given access to their marks or other feedback after the quiz has been closed.

This kind of more summative test is needed to establish an individual's performance either partly through or at the end of a learning cycle. For such tests to be fair, the student must already be familiar with the CAA system concerned. Care must also be taken that the possible random values for parameters lead to equally challenging questions. Internet access to these tests allows for large classes to sit these tests simultaneously from different computer clusters on the campus.

6 Integrating AIM into a learning environment

It is essential that a course provider carefully considers the integration of CAA into the learning environment of the student. A package like AIM opens up a variety of possible uses in the context of teaching and the promotion of self-paced learning in a university environment.

The Learning Development Unit of the University of Birmingham is sponsoring a project in the School of Mathematics and Statistics, which investigates how such questions and tests can be integrated in the learning environment associated with a major core module. As a result, web-delivered questions will be used to enhance the tutorial support, encourage the students to practice and to allow feedback loops in the learning cycle to be closed.

First, this core course is concerned to a large extent with basic skills, which are ideally suited for a CAA approach. Second, this course taken by large numbers of students with a varying need of support.

Self-assessment exercises should be integrated with the materials provided on the web, e.g., through links from lecture notes or overviews of content. Beside their contribution to the learning process itself, these exercises also allow the student to become familiar with the CAA system and the answer syntax it requires.

On-line Continuous Assessment quizzes provide a progress structure, encouraging the student to fully engage with the material during term-time. This can be done in a flexible way, from any networked PC at the most convenient time.

Summative assessment then serves to take stock of the individuals ability to answer questions within a prescribed time-frame. These class tests, when delivered during term-time, still have a formative aspect as they do provide feedback to the students prior to the final assessment.

This overall process would benefit from integrating into a Virtual Learning Environment. At Birmingham, WebCT is being tested as the vehicle to provide the web based materials and processes. It may well be an advantage to be able to use the more professionally developed systems for student monitoring and communications inherent to these VLE's and to provide ways of linking to CAA systems like AIM to provide a smooth integration.

Further on, these internet based intelligent CAA systems pave the way for on-line education. Internet access allows for the provision of preparation materials, including assessment, for secondary school pupils intending to study at university. It can help to administer and assess state examinations in minority subjects for which schools can not afford full time support. It makes on line continuing professional development a real possibility.

7 Other developments

Beside the already mentioned AIM and Calmaeth, other systems are being developed and marketed that rely on CAS in one form or the other. Worthwhile mentioning are the efforts made by major publishers to provide on-line assessment tools and banks of questions as an additional feature of their standard textbooks. Brownstone Learning (see [12]) is currently working on a Maple based assessment tool, of which the details are still confidential. They are providing software solutions, including eGrade to John Wiley & Sons. Pearson Education has the copyright on MathXL (see [14]), which is used by Addison-Wesley and uses webMathematica. Weblearn (see [13]) is also making use of Maple in its assessment tools. These professional products may be able to deliver neater administrative interfaces, but it is important that the flexibility that systems like AIM offer is not lost.

8 Conclusions

Intelligent Computer Aided Assessment provides the educator with assessment options that can be tailored to particular learning environments. In the past, the learning context was often determined by the restrictions imposed by the CAA system. The ability to administer CAA over the internet makes it possible to cater for the whole gamma of learning support activities, from tutor led and time-tabled sessions to real self-paced learning by the students.

Systems like AIM open up a new area of research into how computer aided assessment can be used to measure and stimulate the understanding of mathematical concepts. Where a vast literature exists regarding the use or abuse of multiple choice questions, little has been done on the issues related to more open-ended computer aided assessment. Systems like AIM, which build upon a computer algebra package, allow us to set and assess questions that we might otherwise avoid even in paper based tests, see, e.g. [4].

Computer aided assessment tools linked to computer algebra packages constitute an important new development in making mathematics accessible over the internet. With many current developments, some exciting new tools for educators in mathematics will emerge.

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