Editorial

Are the times changing back again?

Some of you will remember the 1992 movie *Bob Roberts*. It was the story of the rise to power of a corrupt, ultra-conservative (American) politician. And one of his most cunning campaign strategies was to use as his theme song, a clever backhander to Bob Dylan, ‘The Times Are Changing Back Again’.

In science education circles in the late ’80s and early ’90s there was a general feeling that, because of the advent of the new Information Technologies, the times really were a changin’. It was commonplace to aver that IT would change, not only how science was taught, but also what science is taught. That hasn’t happened — at least not yet. With a few notable exceptions, universities are now teaching courses very similar to what they taught then, but with the content brought up to date. Information Technology is still with us, but it is very much just part of the background. Just one aspect of the flexible way we teach science in this decade.

The same is true within the community of dedicated tertiary science teachers to which readers of journals like this belong. Much of the emphasis in teaching innovation has shifted from exploring what IT can do, to research into how students learn (from any and all teaching methods). In this issue of *CAL-laborate* for example, four of the six articles concern innovations which are software based: two are about evaluations of student learning, which depends at best peripherally on computers.

This trend must be seen as healthy. Our main concern must be how understanding is constructed inside our students’ heads. Information technology is but a communication channel through which we try to intervene in this process. Nevertheless, I, for one, believe we should also continue to think about what is new in our profession. Things really are different now. Few of us would wish to revisit on our students the bad aspects of the education we ourselves experienced. If the times really are hanging back again, let’s hope it’s not that far back.

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The effectiveness of the Thai traditional teaching in the introductory physics course: A comparison with the US and Australian approaches

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Introduction

In recent years, a substantial and growing body of research in physics education has been involved with identification of student misconceptions especially in the fundamental physics. Misconceptions are ideas or concepts that students have developed, based on their own experiences, which are often in conflict with the physics point of view. For example, many students believe that if an object is in motion, there must be a force acting on it. It is commonly accepted among researchers in this field that such students have failed to develop a Newtonian way of thinking about mechanics, which is the view held by the physics community. (A collection of the important papers in this field can be found in Pfundt and Duit (1994).) Researchers have shown that misconceptions are widely shared, the same ones appearing again and again in different groups of students. They have also shown that traditional instruction is relatively ineffective in correcting these misconceptions or in helping students develop a more ‘appropriate’ way of thinking (see for example, McDermott (1990)).

In the last decade or so, much work has been done on developing special diagnostic tests to uncover misconceptions and to investigate students’ understanding of physics concepts — see for example, Hestenes (1998). These tests usually consist of multiple choice questions in which the correct answer is hidden among very attractive wrong answers. These wrong answers are, in fact, constructed from common misconceptions identified by earlier researchers. Among the best known of the physics tests in the area of dynamics and kinematics are: the Force Concept Inventory (Hestenes, Wells and Swackhamer 1992); the Test for Understanding Graphs in Kinematics (Beichner 1994); and the Force and Motion Conceptual Evaluation (FMCE), designed by Sokoloff and Thornton (1998). Much effort within the Physics Education Research community has gone into evaluating these tests, both by themselves and in relation to one another (see for example, Huffman and Heller (1995)).

Administration of these standardized tests to many groups of students (mostly within the USA) has led researchers to the conclusion that (1) in general, the understanding of concepts in mechanics by introductory physics students is quite poor, and (2) that this low level of understanding is not much improved by the standard teaching given in most universities — so long as the teaching is ‘traditional’, i.e. consists mainly of lectures and laboratories. On the other hand, where innovative teaching methods, usually referred to as ‘interactive-engagement’ methods, are used, considerable gains can be achieved. For a definitive review of all these findings see Hake (1998).

The current authors are interested in whether these same general findings can be extrapolated to other cultures, or whether they are only really applicable within the USA. We focus attention on one of the above standardized tests, the FMCE, because the originators of that test have also developed a particular interactive-engagement teaching technique which targets the same concepts as the test addresses. Reports of the testing of their own students can be briefly summarized thus. (1) The great majority of these students entered a university without a correct, or Newtonian, point of view on kinematics and dynamics, and (2) after instruction by the new teaching method, some 80-90% of their students were able to
complete the FMCE successfully (a much higher fraction than in parallel, traditionally taught classes). See Sokoloff and Thornton (1997) for details. Some teachers in other institutions have used the same methods and report similar results (Cummings et al. 1999).

In Australia, Johnston and Millar (2000) did the same experiment and found comparable results, with one major difference. When the test was administered to introductory physics students before any instruction had taken place, the students’ understanding of the concepts (as measured by the FMCE) was markedly higher than for US students. Since the universities involved in all these trials seemed to be much the same as regards entrance requirements and so on, this finding is interesting, though its significance is not clear.

For many reasons therefore, it would seem important to ask whether these findings are valid only for Western educational systems, or whether they are also likely to apply to, for example, the educational system in South East Asia. As a first step in answering this question it was decided to test students in a non-Western context in order to study their pre-university level of understanding and the effectiveness of traditional teaching. The same FMCE test was given, before and after instruction, to 1300 physics first year students at Mahidol University in Bangkok, Thailand.

The Force and Motion Conceptual Evaluation (FMCE)

The FMCE is a research-based multiple choice assessment instrument that was designed to probe a conceptual understanding of Newtonian mechanics. It consists of 43 questions, which are divided into 8 sets. Thornton and Sokoloff (1998) focused on the following four sets of the test.

Set 1: Natural Language Evaluation (questions 1, 2, 3, 4 and 7). This set consists of five force-sled questions, asking students to relate a force to various motions of the sled. All the questions make no reference to graph or coordinate system. The questions in this set are as follows.

1. Which force would keep the sled moving toward the right and speed up at a steady rate (constant acceleration)?
2. Which force would keep the sled moving toward the right at a steady velocity?
3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)?
4. Which force would keep the sled moving toward the left and speed up at a steady rate (constant acceleration)?
5. The sled is moving toward the left. Which force would slow it down at a steady rate (constant acceleration)?

Set 2: Graphical Evaluation (questions 14, 16, 17, 18, 19, 20 and 21). This set uses graphical representation in the answers and does not explicitly describe the force that is acting on an object. All questions are asked in the same way as those in set 1, so they measure the same concepts in physics.

Set 3: Coin Toss (questions 11, 12 and 13). This set of three questions asks students to select a force acting on the coin tossed straight up into the air. The questions in this set are as follows.

11. The coin is moving upward after it is released.
12. The coin is at its highest point.
13. The coin is moving downward.

Set 4: Cart on Ramp (questions 8, 9 and 10). This set of three questions is similar to set 3 except that the situation is changed from a coin tossed into the air to a cart pushed and released up the ramp.

Full detail of the test as well as deeper discussion and analysis of the test can be seen in Thornton and Sokoloff (1998).

The translation

English is not the native language of Thai people. Many Thai students have problems with English questions. Therefore, it is impossible to use the FMCE test with Thai students without translation. The translation was carefully done by an experienced Thai physics professor at Mahidol University. He has done many translations of English physics problems into Thai ones. The Thai version of the test uses technical terms understandable by first year students. Each question was translated in the way that all its original meanings are kept and no further explanations are given. The translation into Thai was validated by 20 academic staff and graduate students in the physics department at Mahidol University. They were asked to do both Thai and English versions of the test. The Thai test was given first and then the English test. Therefore, the staff and students had no chance to translate the test on their own. With minor adjustment of the translation, all of the staff and students arrived at the same answers for each question in both Thai and English tests. In other words, if a person made a mistake in one of the questions in the Thai test, he also made the same mistake in that particular question in the English test.

The experiment

We have done the test at Mahidol University, which is one of the best universities in Thailand, especially in the fields of science and medical science. The first year calculus-based physics course at Mahidol University enrols around 1300 students. The students major in medical science, engineering and pure science. They were generally divided into 6 classes. Each class had roughly 200 students and was taught by different lecturers. The physics course in the first semester consists of four topics: Mechanics, Waves, Thermodynamics and Electromagnetism. The 12 hours of Mechanics take 6 weeks of lectures.
The students were asked to do the FMCE test during the first week of the first semester before the traditional instruction was given. The Mechanics lecture lasted 6 weeks and covered dynamics, kinematics, work, energy and rotation. The traditional instruction includes standard lectures, homework problems, and quizzes. The students also enrolled in a separate course of physics laboratories with weekly experiments. The students were told that test results had no effect on their grades, but they would get a few points in reward for doing the test. Three weeks after the end of the Mechanics lecture, which is also one week after the regular mid-semester examination, the students were given the same test again.

Results and discussions

The pre-test results of the experiment are shown in Figure 1 in which student responses are reported for four sets of questions.

![Figure 1](image)

**Figure 1.** The percentage of correct responses in the pre-test from 1300 students at Mahidol University

The first point to be noted is that around 40% of the students answered the dynamics questions in set 1, the natural language evaluation, in the ways that are consistent with a Newtonian view of the world. The graphical evaluation that roughly asks the same questions, yields lower percentage. This is possible owing to the lack of practice on the graphical part of dynamics for Thai students.

For the coin toss and the cart on ramp sets of questions, we follow Thornton and Sokoloff (1998) by considering that students have the Newtonian point of view only when all three questions in each set are answered correctly. The results of these two sets (see Figure 1) show that less than 20% of the students have the Newtonian point of view.

For detail of the distribution of marks on selected test items, we choose to show percentage of students getting the correct answer in each question of set 1 and set 3. This is shown in Figure 2.

![Figure 2](image)

**Figure 2.** Pre-test and post-test percentages of correct responses to questions in set 1 and set 3

Low scores in question 2 of set 1, both in pre- and post-tests, indicate students’ misconception in relating force with motion even when the sled is moving at constant velocity. Relatively low scores are also found in all questions of set 3, especially question 11. The changes before and after traditional instruction averaged about 9.0% and 9.8% for set 1 and set 3 questions, respectively. Such low improvement on these questions may be due to the wrong
assumption of the teacher that students have already had the right concept about force and motion before entering the university. (The teacher was not provided with the pre-test results before giving the lecture). The results also indicate that most of the students still use their own concepts and do not accept the Newtonian point of view. They somehow relate the direction of force with the direction of motion.

Figure 3 shows the student understanding before and after traditional instruction for all sets of questions. It is clear that the lecture has small effect on student understanding since the total change before and after traditional instruction is about 9.7% in average. This is quite a low gain after the traditional instruction was given although there is a big room for improvement due to the low pre-test scores.

Comparison of the pre-test scores of Thai, Australian (Johnston and Millar 2000) and US (Thornton and Sokoloff 1998) students on the same sets of questions is shown in Figure 4. All four sets of question show the same trend. The pre-test scores of Thai students are between the US and Australian. The average of the pre-test scores for US, Thai and Australian are 9%, 27% and 49% respectively.

![Figure 3](image1.png)

**Figure 3.** Comparison of the percentage of correct responses before and after traditional instruction at Mahidol University

![Figure 4](image2.png)

**Figure 4.** Pre-test percentage of correct responses to questions in four sets, as published by Thornton and Sokoloff (US), Johnston and Millar (Australian) and at Mahidol University (Thai)

A comparison of the gains from the three different contexts is shown in Figure 5. In all cases the student gain was quite low. In fact, the averaged gains are almost the same. They are 8.0%, 9.7%, and 10.1% for US, Thai and Australian students, respectively. The three contexts have similar gain despite the fact that their pre-test scores are quite different. These gains confirm the worldwide-accepted conclusion that traditional instruction is ineffective in teaching physics concepts and in changing misconceptions.

**Conclusion**

We have done the conceptual evaluation test with around 1300 students in a Thai university. The result from the pre-test shows that a few students entering a university understand force and motion from the Newtonian point of view. After a semester of traditional instruction the improvement in performance is found to be quite poor. There was an increase of only 10% from the pre-test scores. Such results have also been found in universities and
colleges in the US and in Australia, as reported in the literature (Thornton and Sokoloff 1998; Johnston and Millar 2000). The findings of this project therefore support the widely held view that traditional teaching is relatively ineffective in helping students to learn physics concepts and in changing misconceptions. It is also interesting that the average of the pre-test scores in the Thai context is 27% which is lower than for Australian students but higher than for US students. Again the significance of this is not clear and calls for further investigation.

We believe that it is possible to conclude that the 10% improvement points to the ineffectiveness of traditional teaching on mechanics, in Thailand as in the USA and Australia. The second stage of this project must therefore be to test whether a significant improvement in understanding (as measured by the MFCE) can be achieved by replacing traditional teaching strategies with more interactive learning ones (see, for example, Sokoloff and Thornton (1997) and Johnston and Millar (2000)).

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Computer-aided assessment in mathematics: Panacea or propaganda?

Abstract

The proponents of computer-aided assessment are very persuasive in extolling the benefits and virtues of this technology. Undoubtedly, it has many positive features. However, it also has some limitations and drawbacks which need to be considered. Mathematics as a discipline has certain specific problems which are not relevant to the use of computer-aided assessment in many other disciplines. These problems often feature the introduction of the assessment of other learning outcomes into the process. This can create problems in summative assessment but is less of a problem in formative assessment. Evidence is supplied that students find the use of computer-aided assessment in a formative manner to be worthwhile. Finally, a key question about the future development of computer-aided assessment in mathematics is posed.

Introduction

Computer-aided assessment has a number of indisputable benefits which include:

• availability – students can take assessments whenever they can access the network on which the tests are mounted;
• immediate feedback – as soon as students have completed their test they are given, not only their mark, but also feedback (as detailed as the test author wishes) on the questions they answered incorrectly;
• repeated practice – provided a question bank of similar questions has been authored, students can take tests on the same topic repeatedly to develop their skills; and
• anonymity – some students feel more secure giving answers to an inanimate machine than to a human being – there is less embarrassment in giving a foolish answer when it is only the machine that ‘knows’.

The proponents of computer-aided assessment will extol these undoubted virtues. However, there are some pitfalls with computer-aided assessment, particularly in mathematics, which academics need to consider before they decide whether it is worth investing their time in preparing and using computer-aided assessment with their students.

In the United Kingdom, the Quality Assurance Agency, the body responsible for the quality of higher education programs, has steered universities firmly in the direction of constructive alignment with a greater emphasis than ever before on the role of assessment1. Programs are required to demonstrate that all the intended learning outcomes for the program are assessed. Indeed, failure to assess one of the learning outcomes is one of the few specifically identified grounds on which reviewers would deem the standards to be inadequate.

The QAA approach implies a hierarchical structure. Program outcomes are secured by a combination of the outcomes of the modules or units which make up the program. The assessment scheme for each module must ensure that all the intended outcomes of the module are assessed. This requires that each assessment task within the module should identify the outcomes it is assessing, to ensure that all outcomes are assessed. Of course, some module outcomes may be assessed by more than one assessment task and some program outcomes may be assessed in more than one module.

The use of computer-aided assessment as a delivery mechanism for a specific assessment task should ideally have no effect on the outcome being assessed. However, this does not automatically happen and care must be taken to ensure that
using computer-aided assessment does not introduce extra outcomes to the assessment task or allow the assessment to be completed satisfactorily in a way which does not require the achievement of the outcome being assessed.

In subsequent sections examples where the use of computer-aided assessment may cause problems are highlighted. In most cases these problems are not insurmountable, but it is vital for the sake of the reliability of the assessment that they are considered.

**Multiple choice and guessing**

The easiest question type to implement in computer-aided assessment is multiple choice. Multiple choice questions do not require a complex software package for their implementation – indeed they can be constructed quite easily using standard HTML forms.

Some academic staff have reservations about the use of multiple choice questions. They argue that candidates who have no understanding at all of the subject matter of the question have a chance of getting the question right by simply selecting at random one of the choices offered. Although, in principle, increasing the number of options available reduces the likelihood of a successful guess, the difficulty of producing plausible incorrect answers means that in most cases only a small number of options are given. Furthermore, the form of the choices may give candidates, who otherwise did not know how to begin, an indication of the method required to solve the problem.

One method that is often used to combat the possibility of students guessing the correct answer is negative marking. If a multiple choice question has four options (one correct and three incorrect) then one mark is awarded for a correct answer, whilst one-third of a mark is deducted for an incorrect answer. The idea behind this is that the expected value of a student answering the question at random is zero. This is attractive, however it does penalise the student who genuinely makes a mistake. In a pen and paper examination a student who makes a mistake and so produces an incorrect answer would, at worst (there may be some method marks), be given a mark of zero. In a multiple choice examination with negative marking this student is actively penalised for her/his mistake.

Proponents of multiple choice testing counter the charge that guessing may invalidate the assessment by pointing out the importance of having a reasonably large number of test items. The following is a quote from Blueprint for CAA:

> ‘It’s worth remembering that the relevance of guessing decreases as the number of test items increases. If you have a true/false test containing ONE question, a student has a 50% chance of getting it right and scoring full marks. The chances of scoring 100% on a 45 question true/false test are less than one in a trillion \((10^{12})\) and the chances of earning at least 70% in a 45-question test are less than one in 300.’

In actual fact these are the probabilities for a 40 question test (for a 45 question test the chances are respectively less than one in 35 trillion and less than one in 800).

However, such arguments obscure the point. Most students do not randomly guess all questions but only some. Instead of considering a student who knows nothing and guesses everything, it may be more appropriate to consider the fate of marginal students (i.e. those who would just pass, or just fail, a pen and paper test). In particular, it is more revealing to examine the likelihood of marginal students passing a multiple choice test when they would have failed a pen and paper test, rather than the chances of a complete random guesser achieving 70% or 100%.

Consider two weak students taking a 40 question test with a 40% pass mark. Student A has only focused on a small part of the syllabus and so only knows how to attempt 17 of the questions of which 14 are answered correctly. Student B has focused on a slightly larger part of the syllabus, attempting 24 questions, although only 16 of these are answered correctly.

If this is a standard pen and paper test with one mark for a correct answer and zero otherwise (no fractional marks for method) then student A scores 35% and fails whilst student B scores 40% and passes.

Now look at the fate of these students taking the same questions but taken as multiple choice questions. We will assume that the questions they answered incorrectly are still answered incorrectly (i.e. the presence of the multiple choice options does not help them to correct some of their incorrect answers) and that they randomly guess the answers to the questions they do not know how to attempt.

If the straightforward zero/one marking scheme is retained student A needs to guess correctly the answers to two questions out of 23 in order to achieve a pass mark of 40%. With four multiple choice options the probability of doing this is almost 99%.

If negative marking is employed, so that the student is penalised by one-third of a mark for each wrong answer, the student needs to gain three marks from guessing in order to pass. This requires at least eight correct answers from the 23 guesses. Clearly this is a less likely event; but it still occurs 20% of the time.

Student B, when taking the test with pen and paper was the most marginal pass student possible. When taking this test using zero/one multiple choice the student has a 60% chance of gaining a mark of over 50% (by correctly guessing the answers to at least four out of 16 questions). However, if negative marking is used, this student (who is clearly better prepared than student A) is in considerable difficulty. The eight incorrect answers and consequent loss of 8/3 marks means the student must guess correctly the answers to six of the remaining 16 questions in order to regain the lost marks and register a pass. This will happen 19% of the time. So 81% of the time student B will fail the test although 40% of the questions were answered correctly from the student’s knowledge and not because of guessing.
The fates of student A and student B demonstrate some of the inherent problems associated with multiple choice tests.

**Introduction of extra learning outcomes**

The software available to deliver computer-based assessment has advanced significantly over recent years. However, it still has and almost certainly always will have some limitations. Academic staff are creative in finding ways round these limitations – however these ‘fixes’ can introduce extra learning outcomes into the assessment process.

For example, a standard question to assess the learning outcome ‘is able to solve quadratic equations’ would be:

\[
\text{Solve the quadratic equation } 2x^2 + 3x - 2 = 0
\]

However, in the computer-aided assessment package produced by Ward and Lawson\(^3\), this question becomes:

\[
\text{What is the larger root of the quadratic equation }
2x^2 + 3x - 2 = 0?\]

The reason for this change is that *Question Mark Designer*, the software used to produce this assessment package, does not allow questions whose answers are unordered lists. Although the change to the question is only minor it has introduced the implicit assessment of an extra learning outcome into the question. In order to be able to answer the question correctly the student must not only be able to find the two solutions of the equation but also be able to order them correctly. Now it may be argued that this is a relatively simple task that should be well within the compass of anyone who can correctly solve the quadratic equation. However, there is scope for error, particularly when both solutions are negative. Occasionally a student who would have correctly answered the question on paper will give the wrong answer.

There are other simple variations of this problem. Hawkes\(^4\) suggested that one way of delivering a question which required the student to determine the coordinates of the maximum point on a given curve was to ask for the sum of the squares of the coordinates. Again the thinking is that any student capable of using calculus to find the location of the stationary points and then to determine which is the maximum would be perfectly capable of squaring the two coordinates and then adding the two squares. However, even able students do sometimes make arithmetic slips. Once more a learning outcome has been added in order to allow the question to be delivered by computer rather than on paper.

Both these examples are caused by limitations in the software used to implement them. In mathematically focused software, such as that described by Beevers and Paterson\(^5\), answers which take the form of unordered lists (required for the quadratic equation question) and ordered lists (required for the maximum question) are allowed. With such software these particular problems are solved. However, this does not mean that the problem of the introduction of extra learning outcomes into the assessment process has been eliminated. It simply means that it has been pushed further along (as we shall examine in subsequent sections).

**The input of mathematics**

Computer-aided assessment in mathematics has two major difficulties that are not present in many other disciplines. The first is how to enter mathematical expressions, particularly when the standard formatting of these expressions requires more than a single line (such as with fractions, powers, etc.). The second is the way in which mathematical expressions are checked to determine if they are correct. As this second difficulty does not impact particularly on the assessment experience it is not discussed further here.

In the early days of computer-aided assessment in mathematics, questions requiring mathematical input used linear input. Such linear input was based broadly on the kind of syntax students would have encountered in spreadsheets\(^6\). This meant that students had to be competent in this form of representation of mathematical expressions in order to be able to complete successfully computer-aided examinations. Now it is desirable to expect students to use standard mathematical notation and formatting when producing written answers – indeed this is an essential skill that students must have and one that has been implicitly assumed to be an assessed learning outcome of every written mathematics assessment. However, it is completely different to require mastery of non-standard syntax (it is non-standard because different assessment packages used different versions – for example, should exponentiation be denoted by ^ or by **?).

For this reason specifically mathematical assessment packages have developed their own input tools (see, for example, Beevers and Paterson\(^7\)). These tools vary. Some still use linear input but then present the formatted representation of the linear input so that students can check that the input they have given does represent the answer they wish to enter. If it does not then they can edit the linear input and check the new formatted representation and repeat the process until they have successfully entered their answer. Other input tools use palettes and templates in a manner similar to *Equation Editor* within *MS Word*. With this approach the student builds up the formatted version of their answer directly rather than indirectly via linear input. Whilst both of these methods are to be preferred to linear input on its own, they still place extra learning requirements on the student. These learning requirements are nothing to do with the learning outcomes of the program or the piece of assessment. They are simply to do with the mechanism being used to deliver the assessment.

As the entire population becomes ever more computer literate it may well be that this problem will disappear. We do not say that because a pen and paper assessment requires students to be able to write that we have introduced extra...
learning requirements. So, when everyone is completely familiar with building up formatted expressions from palettes and templates, we will be able to say the same about input tools.

**Multiple choice: Another problem**

One way of avoiding the need to have an input tool for questions with answers that require formatted mathematical input is to use multiple choice questions. Ward and Lawson use this device in some integration questions.

So, instead of asking the question:

\[
\text{Use the substitution } u = 1 + 3x \text{ to determine } \int \cos(1 + 3x)dx
\]

the question is presented as:

<table>
<thead>
<tr>
<th>Option</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( \frac{1}{3} \sin(1 + 3x) + c )</td>
</tr>
<tr>
<td>B</td>
<td>( \sin \left( \frac{1 + 3x^2}{2} \right) + c )</td>
</tr>
<tr>
<td>C</td>
<td>( \frac{1}{3} \cos(1 + 3x) + c )</td>
</tr>
<tr>
<td>D</td>
<td>( \frac{1}{6} \sin(1 + 3x)^2 + c )</td>
</tr>
</tbody>
</table>

In this question, there is no need for students to enter a mathematical expression. All that is required is for them to determine the integral and then find their answer amongst the options offered. This question may have been designed to assess the learning outcome ‘is able to determine indefinite integrals of standard functions of linear functions’.

Even if a student answers a large number of questions like this correctly, the assessor has no guarantee that the student has achieved this learning outcome. The reason for this is that the student may not be determining any integrals. Instead students may simply take each of the choices offered and differentiate them until one whose derivative matches the integrand in the question is found. Such students have learnt some mathematics (namely differential calculus), but not the mathematics supposedly being assessed (namely integral calculus).

**Method marks and partial credit**

One particularly difficult issue in attempting to replicate pen and paper assessment in mathematics using computer-aided assessment is the allocation of method marks and partial credit. Although an industrial speaker at a mathematics assessment conference once said,

‘There are no method marks in industry’,

this message has fallen on deaf ears. It is generally accepted throughout the mathematics community that an incorrect answer can still demonstrate the achievement of some learning outcomes and should therefore be rewarded with some (although not all) the marks available.

Method marks are most commonly awarded in questions requiring a multistage solution process. For a simple question such as, ‘What is the value of \(-8 + 3\)?’, method marks would not usually be available. But in a question such as, ‘Find and classify the stationary point of \(y = (x+1)\exp(-2x)\)’, method marks and partial credit would usually be available. Method marks would be awarded to a student who demonstrated that they knew (at least some of) the steps to undertake to solve this problem (even if none of them were carried out correctly). Partial credit would be awarded to students who knew the way to proceed and carried out some of the steps correctly.

In order to award method marks and partial credit it is necessary to have some knowledge of how the student has approached the problem and what some of their intermediate results were. One way to do this using computer-aided assessment is to replace the single large problem with a series of smaller questions.

Beevers and Patterson give an example of this approach for a typical question from the school-university interface, namely:

Obtain partial fractions for \( \frac{x}{x^2 - 1} \), \( x > 1 \)
Students can elect to answer this in stages rather than giving the complete answer initially. In this approach they are prompted with a series of steps, each of which they must answer in order to determine the solution of the original problem. In this example the steps are:

**STEP 1:** Factorise the denominator of \( \frac{x}{x^2 - 1} \)

**STEP 2:** If \( \frac{x}{x^2 - 1} = \frac{a}{x + c} + \frac{b}{x + d} \) where \( c < d \), then by finding the common denominator, state the right hand side of the equation which equates the numerators

**STEP 3:** By equating coefficients of \( x \), state the expression equal to 1

**STEP 4:** By equating constants, state the expression equal to 0

**STEP 5:** What is the value of \( a \)?

**STEP 6:** What is the value of \( b \)?

It is undeniable that this approach does indeed give students the opportunity to achieve partial credit. However, it is also true that this approach has altered the assessed outcomes when compared with this question delivered during a pen and paper examination. Firstly, candidates no longer have to know what partial fractions are as the question now displays the partial fraction decomposition. Secondly, as discussed in the section titled 'Introduction of extra learning outcomes', an extra learning outcome, that of correctly ordering numbers has been introduced. Thirdly, candidates do not have to know an algorithm for determining partial fractions – instead they simply have to respond to the prompts which steer them through steps which will lead to the determination of the partial fractions. Fourthly, candidates must use the expected method – a student who has learnt to find the coefficients in partial fractions by using the ‘cover-up’ rule may not know how to respond to some of the intermediate steps that have been built into the delivery of this question. As assessors we may be willing to accept the changes in the outcomes being assessed that the move from pen and paper assessment to computer-aided assessment has made (after all, pen and paper assessment is not perfect); however we should not be ignorant of these changes.

Assessors, irrespective of the medium they are using to deliver their assessment, should be clear about precisely what they are seeking to assess. Consider again the question, ‘Find and classify the stationary point of \( y = (x+1)\exp(-2x) \).’ If this is set in a pen and paper examination precisely what is being assessed? To answer the question correctly a candidate must find a derivative using the product rule, solve an equation by factorisation, find another derivative by using the product rule, evaluate an expression and use information about the second derivative to determine the nature of the stationary point. Furthermore they must know that these are the steps to go through in order to solve this problem. It is this ability to know and work through a set of connected steps that is at the heart of this assessment. All of the skills required for the individual steps can be assessed with other questions. For example, if all that was to be assessed was that a student knew how to determine the nature of a stationary point then it would be better to ask the question, ‘If \( \frac{dy}{dx} = 0 \) when \( x = a \), how can you determine the nature of the stationary point at \( x = a \).’ This has implications for the computer-aided assessor in terms of how the question is constructed but also for the pen and paper assessor in terms of the allocation of partial credit. Many marking schemes for such a question would award marks for correctly determining each derivative (although this is assessment of the same skill) and also for correct evaluation of the second derivative at the stationary point (which is really a much lower level learning outcome than this question is aimed at). Perhaps there is some merit after all in the view, ‘There are no method marks in industry’!

**Assessing higher level outcomes**

McCabe et al. have attempted to show that computer-aided assessment can be used to assess some higher level outcomes. They have developed questions aimed at assessing students’ abilities to formulate mathematical proofs. One such question gives eight statements that constitute a proof by induction of a property of trees. The statements are given in a random order and candidates are required to put these statements into the correct order. Another proof question is shown in Figure 1.

Whilst this is undoubtedly imaginative use of current technology it certainly cannot be thought of as equivalent to asking a student to prove from scratch that \( (AB)^{-1} = B^{-1}A^{-1} \). To assess whether a civil engineer can design a bridge we do not give the engineer a set of components from a dismantled bridge and ask them to indicate how they should be assembled. This is not to say that such questions are without value. Indeed they may serve a very useful purpose in learning some general points about how to construct a proof.
Students who are concerned to maximise their marks rather than their learning may develop strategies for answering questions such as that shown in Figure 1. Such strategies may include things like, ‘Proofs often begin with “Let” and then make use of definitions’, and, ‘When we are trying to find something composite we begin by replacing it with something simpler’. These strategies would help them to identify some of the early stages of this proof as E5 (‘Let’ followed by ‘X=(AB)^{-1}’ – the composite that we are trying to prove something about replaced by something simpler), then Bn (using the definition). A further strategy could be, ‘The proof ends with the result you have been asked to prove’. This would lead to the conclusion that Line 5 must be $z_3$. So far no knowledge of the topic area under consideration has been used but four out of the 10 fragments have been correctly placed. In terms of assessing candidates’ ability to prove results about matrix inverses this is not particularly satisfactory. In terms of students learning about the general ideas of proofs, these strategies are very valuable.

**Why bother?**

Given the list of difficulties associated with computer-aided assessment that has just been outlined, it is reasonable to ask the question, ‘Does this mean that computer-aided assessment in mathematics should be abandoned?’. The answer to this question is a definite ‘No’. Students derive great benefit from attempting questions and getting immediate feedback on their answers (not just right or wrong but also an indication of how to obtain the correct answer if they were wrong). Practically the only way that this can be delivered on a large scale in higher education today is through the use of computer-aided assessment.

At Coventry University there is a drop-in Mathematics Support Centre which is open for 33 hours per week. Students come to the Centre to receive one-to-one help with problems in mathematics. The Centre also has a web site where students can download copies of all the handouts that are available in the Centre and take practice tests in a range of topics from arithmetic to calculus. Figure 2 shows the usage of the web site during the academic year 2000/01. By far the most used section of the web site is the online test section. In each of the last two months of the academic year almost 800 online tests were taken each month (compared to around 400 in person visits per month to the Centre). As all these test attempts are purely voluntary and completely formative (no record of who attempts the tests or what marks they gain in the test are kept), this indicates that the students certainly perceived value in this computer-aided assessment.

**Conclusions**

The truth about computer-aided assessment in mathematics is that it is neither a total panacea or simply propaganda. It does have limitations but there are circumstances in which it is very valuable.

Most of the limitations discussed above are of greatly reduced significance when the assessment is formative rather than summative. In such circumstances the problem of negative marking for multiple choice questions is largely irrelevant as the point of the assessment is not to determine a mark but for the students to find out for themselves how well they know the material being tested. Likewise, the problem with students working back from the multiple choice options to the answer (as in the integration example...
in the section titled ‘Multiple choice: Another problem’) is less significant. If what is being assessed formatively is made clear then the main losers if the question is approached in the wrong way are the students themselves as they do not gain the information about their competence in integration that the assessment was designed to give.

Although the benefits of computer-aided assessment are most easily secured in formative assessment this does not mean that it cannot be used summatively. More care is needed to ensure that the assessment is robust and reliable, but this is possible. Summative use of computer-aided assessment for basic skills testing is well documented (see, for example, Beevers et al.\(^1\)) and Beevers et al.\(^{11}\).

One of the key issues now is whether to continue to seek to develop computer-aided assessment in mathematics to attempt to assess higher level skills or whether to accept that for the foreseeable future this can only be done through pen and paper assessments. Workers in this field must ask themselves some hard questions. It is undoubtedly intellectually challenging to seek creative and imaginative ways of using ICT to deliver assessment in mathematics. On the other hand, it is not very stimulating to mark a pile of student manuscripts. However, as time is a finite resource, we must ask if the returns from further advances in computer-aided assessment in mathematics are worth the resources that will have to be invested to achieve them. To put it bluntly, ‘Will my students benefit more from me spending \(x\) hours marking their written work (in formative or summative assessment) than from me spending the same \(x\) hours experimenting (with uncertain outcome) in computer-aided assessment?’.

![Number of Hits](image)

**Figure 2.** Usage of online tests at Coventry University Mathematics Support Centre web site (from Lawson et al.\(^2\))

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A way of teaching statistics: An approach to flexible learning

Introduction

Over the past few decades there has been a debate about the reform of statistics education. In particular, many educators are interested in finding a better answer to the question, ‘How can students’ learning be improved in statistics education?’. Although modern statistics has many visible applications as well as a high demand in employment, students are still moving away from learning statistics. Since the reason for this is not very clear, we must tell the students (and potential students) that statistics forms a strong basis or foundation for many fundamental and experimental studies apart from standing on its own as a discipline. Since most of the theories in statistics are based on mathematics, teaching statistics becomes more difficult than other subjects. Teachers need to find better ways to resolve these difficulties in teaching and answer the common question, ‘Why do students need to learn theoretical statistics via mathematics if statistics is supposed to be rich with applications?’. It is, indeed, a very difficult question to answer, i.e. like making a journey in a cart (statistics) without a horse (mathematics).

What is statistics?

Statistics is a discipline or a branch of mathematics dealing with the collection, analysis, interpretation, and presentation of data from any random experiment. These data or observations fall into two categories called qualitative and quantitative. Each observation is considered as one of the values from a set of all possible values. Hence, this observation is considered as a value of a random variable. Due to this uncertainty of outcomes of an experiment, the concept of probability theory is required to understand the basics of statistics. Based on these views, many elementary statistics courses cover the topics; random experiments, data collection, summarizing data in tables and graphs, some important measures for location and dispersion, relative frequencies and introductory probability, some important discrete and continuous probability distributions, normal distribution, sampling theory, statistical inference, goodness of fit tests, and correlation and regression.

Before beginning to teach a topic from the syllabus we must tell the students ‘what’s the use of this topic in statistics and what sort of situations are there to apply this in a real world situation’. As mentioned before, the concepts in statistics are developed around ‘randomness’ or ‘uncertainty’. Like in many parts of mathematics, in statistics our main aim is to find the best model for a particular pattern of observations. Here the word ‘best’ means with ‘least uncertainty’ or ‘more confidently’. It is anticipated that no one can predict an outcome or result of an experiment with 100% confidence. Due to these reasons, statistics becomes an abstract subject, and hence, getting students motivated can be very challenging. However, properly motivated students will have, indeed, a ‘deep learning ability’ which is usually the ‘learning with pleasure’ that lasts forever. There are a number of possible ways to handle this situation. Some of them are given in the next section.

Effective teaching and flexible learning

Very often teaching and learning at the university level seems to be focused on students passing the prescribed assessments/examinations and gaining (at least) the minimum credentials for the required degree. It is clear that in such an environment, long-term objectives of teaching or learning are unattainable. This is particularly true for teaching statistics, where a vast majority of students who follow statistics as service courses have no intention to continue as majors.
Teaching is increasingly being recognized as a complex and multifaceted product of many variables. All signs point in the same direction – the culture of teaching and learning is changing. Although this evolution is faster in many subject areas, it would be difficult to deny the decreasing visibility (or trend) of teaching and learning in mathematical sciences, in particular, in statistics. This fact is evident in the drop of the number of students in statistics majors in many Australian universities over the past 10 to 15 years.

Effective teaching begins with proper planning. Courses must be planned; chapters and units as well as each class must be planned with carefully chosen material and examples. A complicated topic like hypothesis testing, for example, may begin with a problem from today’s newspaper or from a recent article: suppose that the Government claims that the unemployment rate is 7%, while the opposition parties claim that the government is underestimating this figure to win the next election. Clearly, there is a dispute between these two groups. How can this dispute be solved using statistics? This is a good time to introduce the basic methods that can be used. Now the teacher should define the standard technical terms and procedures in a systematic fashion. An approach like this is more interesting to students than looking at traditional textbook technique (i.e. define the null and alternative hypotheses, etc., etc.). This is evident from the feedback I have received over the past 25 years of teaching mathematics and statistics across a diverse range of countries and cultures. Many topics in statistics can begin with a lively introduction as seen above, followed by slowly explaining the theory. This needs a fair amount of time for planning the teaching schedule. Hence planning stands as the core process of teaching. In each topic one must clearly define the objectives and lay out the most effective way of accomplishing those objectives together with good examples. Always make the assumption that students are in the classroom to learn. Use different strategies to encourage understanding of the relevance of the theoretical materials and classroom work to students’ personal lives. Also, always include many examples and problems for practice in order to reinforce difficult concepts via real world situations.

Concluding remarks

Teaching is itself learning. It is true that teachers always learn more than their students: teachers need to prepare the subject matter well enough to suit the level of students and their learning ability. To learn more about students’ learning capabilities, a constant interaction between students and the teacher is important. Look for signs from students of understanding the material. Usually their body language is a simple and sensible guide to judge the effectiveness of teaching. Another strategy that I use is daily feedback as a constant appraisal process and as an opportunity to respond to any unanswered questions. This is sometimes not possible in large classes. Teachers of large classes are well aware of the challenges that surround teaching several hundred students at once. However, even in large classes, patient teachers can always understand the difficulties that students have by using the approaches mentioned above, or by finding their own ways to teach more effectively according to the situation.

For many teachers in statistics, the archetypal discussion class is not a viable option. In large classes, it is advisable to divide each class into small tutorial groups in order to teach problem solving strategies efficiently. Problem solving is a student-centred approach which provides students with the opportunity to participate, apply knowledge, and receive feedback on their comprehension of the concepts.

The final remark is related to the use of technology in statistics education. Although computers can solve problems efficiently, one should bear in mind that they will never totally replace teachers: the main reason for this is that the numbers or graphs produced by computers do not make any sense without proper explanations. There must be skilled people to interpret and draw conclusions based on computer outputs. This again reinforces for us the importance of statistics education. Computers have become highly integrated into all aspects of academic life and it is difficult to imagine higher education without them. Hence designing any course in statistics must include the use of knowledge of computers and technology to suit the current demand in the job market. Constant interaction with industrial, financial and other relevant institutions is necessary to create up-to-date and modern course design strategies which include the use of computer technology.

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Abstract

This paper was delivered as the plenary lecture at ‘Variety in Chemistry Teaching 2002’ held at the University of Keele, 9th-10th September 2002. It provides a ‘retrospective’ on the 10th anniversary of the start of the Universities Funding Council/Higher Education Funding Council for England (UFC/HEFCE) ‘Teaching and Learning Technology Programme’ and is illustrated by the work of the Chemistry Video Consortium project for 1992-2002.

A set of PowerPoint slides from the lecture is available from the web site http://www.soton.ac.uk/~ecchemed/conference.htm.

Introduction

In 1991/92 the Universities Funding Council (UFC), the precursor to HEFCE, decided that the universities should use more *new technology* in the delivery of learning and teaching. It recognised that for this to happen resources would have to be provided and over the next five years some £50 million was set aside to fund the Teaching and Learning Technology Programme (TLTP). No such initiative has been embarked upon by any other nation.

Project teams were invited to submit bids and three teams were successful in getting bids accepted for Chemistry (see Figure 1), two to start in September 1992, and the other two to start in September 1993. The ‘Variety’ Conference, therefore, coincided with the 10th anniversary of the start of two TLTP projects and it seemed appropriate to look back at what had been achieved.

The strategies adopted by the three Chemistry projects were broadly similar so I will concentrate on the aims, objectives and achievements of the Chemistry Video Consortium project (CVC).

The Chemistry Video Consortium project had the following aims and objectives:

a) to deliver high quality images and resources compatible with 21st century technology – this was an aim common to all TLTP projects;

b) to support learning, teaching and training in the practical aspects of Chemistry; and
c) to provide images and resources for lectures, tutorials, seminars and self-paced learning situations.

As a result of market research, it was decided to concentrate on providing video clips for (b) because of the high investment of time in practical laboratories and the perceived commonality of techniques and experiments across the UK and the world. To fulfill the general needs for images, i.e. item (c), a database of films, videos, laser discs and CD-ROMs was created in collaboration with the Royal Society of Chemistry (RSC) and launched on the RSC web site. This database is regularly updated and a section for pre-16 students has been added to meet the needs of GCSE teachers and students.

**Tips from the Chemistry Video Consortium project**

**Quality**

It was recognised at the outset that the video material would probably be transferred to other platforms and, therefore, the quality of production would be crucial. It was also recognised that students are used to seeing high quality video in wildlife films and documentaries so that to offer low quality video would turn students off rather than turn them on.

To ensure that the videos and resulting products would be of high quality the following steps were taken:

1. videos were filmed at high specification (broadcast quality; Digital D2; Betacam SP) and actors were used for the commentaries;
2. professional directing (OU/BBC director), editing and post-production staff were used;
3. products were designed and made professionally;
4. there was a wide range of authors operating under strict peer review (OU course team model) to ensure generic scripts;
5. detailed preparations were made prior to filming, e.g. storyboards and briefings; and
6. it was essential to have good continuity, e.g. a filming location, a bank of clean equipment, a bank of chemicals.

**Products**

It was recognised that any products must be user-friendly. In 1992/93 the quality of the video images on CD-ROM discs was very poor and so it was decided to use laser video discs to deliver the images in 1995/96. These have the advantage that they deliver high quality video and they can be used with bar codes which provide quick and simple access to clips and parts of clips so that students can troubleshoot problems occurring during laboratory sessions. The response to the laser discs was excellent with more than 60 departments installing laser disc players and using the sets of discs. The key to getting such a high acceptance was ‘road show’ visits in 1993 and again in 1995/96. The former were to clusters of about five university chemistry departments over the period of two weeks. The latter involved visiting each department individually over a five month period when the opportunity to meet a ‘critical mass’ of staff led to incorporation of the laser disc videos into practical classes.

It was discovered that one of the problems with the use of CD-ROMs in the early 1990s was that images had been over compressed in order to put more video onto a particular disc. With better digitisation software and more sympathetic compression a picture quality close to SVHS was achieved in the set of CD-ROMs which was produced in 1999.

An obvious platform for the CVC resources is the Web. However, the high quality video entailed long downloading times for Internet users, complex commercial arrangements and conflicts between management software and user software. Therefore, the currently preferred platform is the stand alone CD-ROM (or DVD). Nevertheless, Intranet access from a dedicated server within an institution’s Firewall is possible and this low cost option produces high quality streaming video. There are, however, problems of conflicting software such that only the videos will stream and the glossaries and the quizzes will not.

Once the images have been digitised and delivered as CD-ROMs there is considerable scope for customising them into new applications (see below) but copyright issues must be settled. Some reasons for customising are:

a) few external resources ever exactly meet the desired need for a particular course;

b) images are costly to produce so customisation affords cost savings by recycling images and this minimises re-inventing wheels;

c) enormous pedagogical benefits arise from building in images, i.e. item (c), a database of films, videos, laser discs and CD-ROMs was created in collaboration with the Royal Society of Chemistry (RSC) and launched on the RSC web site. This database is regularly updated and a section for pre-16 students has been added to meet the needs of GCSE teachers and students.

**CVC resources**

**To date**

The initial product was a series of 19 laser video discs, entitled ‘Basic Laboratory Chemistry’ which was supplied with bar coded booklets. These were converted into CD-ROM format in 1999 and re-titled ‘Practical Laboratory Chemistry’ (19 CD-ROMs).
Once the video images had been converted into CD-ROM format, a series for ‘A’ level entitled ‘Practical Chemistry for Schools and Colleges’ (2 CD-ROMs) was produced in 2000\(^6\) and a series on ‘Physical Chemistry Experiments’ (4 CD-ROMs) was produced in 2001\(^9\).

A collaboration with the Centre Développement Informatique Enseignment Chimie (CIDEIC; University of Nice) has led to the production of a dual language set of CD-ROMs entitled ‘Le bon geste pratique en Chimie/Practical Laboratory Chemistry’ in 2002\(^{10}\). These CD-ROMs were produced using Flash which is more flexible than ToolBook which was used for previous packages. A bonus with the Flash software is that more than one language can be inserted into the software shell and non-Romanesque fonts can be accommodated. This opens up possibilities for a wide variety of packages, e.g. Spanish/English/French, Chinese/English/French. A demonstration CD-ROM covering English, French, Italian, Spanish, American, Brazilian and Russian was produced in September 2002\(^{11}\) to show the multiple language capability and to encourage project teams to get involved with producing packages for their own countries.

In addition to finished products, the CVC team has produced several pilot CD-ROMs. The most interesting is probably one for disabled students which incorporated regular video, scrolling text, subtitles and text with variable font and colour options, quizzes, key stroke operation mode, print out for Braille\(^{12}\).

**Future activities**

The development of the multiple language option indicates that in the future it will be possible not only to export materials with English as one of the multiple languages but also to take packages in other languages and customise them into English, thus avoiding re-inventing wheels.

Given the necessary funding, it will be possible to do the research and development work: to deliver materials in DVD and maybe Internet format, to extend the ‘Chemistry Images’ database, develop resources for disadvantaged students and students with disabilities and to produce new video materials, e.g. ‘Advanced Practical Laboratory Chemistry’. Many of the storyboards for the latter are already written but filming will require about £250,000.

**General needs**

Although it is becoming easier to customise resources, the pressures of time are such that there is actually less time to engage in such activities because of the pressures to do research. Additionally, it is a fact of life that promotion depends on research and not teaching.

How can we deliver the kind of teaching that the TLTP was intended for? The answer is that we must make much better use of the Learning and Teaching Support Network Centre at Hull and the experiences of colleagues across Europe\(^{13}\), e.g. the European Chemistry Thematic Network\(^{14}\).

Another fact of life is that, while the Engineering and Physical Sciences Research Council (EPSRC) provides grants of hundreds of thousands of pounds for research projects, the funding available for teaching is a small fraction of these amounts. If the decline in the numbers of Chemistry students at universities is to be arrested then government agencies, the RSC and multinational companies need to invest imaginatively in innovative teaching projects and in promoting new materials within schools, colleges and universities. Otherwise splendid initiatives like the TLTP will wither away.

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The leap from laser discs to CD-ROMs and then customising new products was carried out by Don Brattan and Oliver Jevons and the development of multiple language CD-ROMs was initiated by Daniel Cabrol-Bass and Jean-Pierre Rabine at the University of Nice.

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**eLABorate**
Enhancing student learning using Decision Support Tools across the curriculum

This paper was first published in CAL-laborate Issue 8, June 2002.

Abstract

A sophisticated commercially available computer Decision Support Tool, GrassGro, has been integrated into the curriculum to enhance teaching and learning at The University of New England (UNE). This computer program permits the simulation of the climate-soil-pasture-animal-economic interactions within grazed ecosystems over long time frames in Australia. This innovation was developed under a national CUTSD-funded (Committee for University Teaching and Staff Development) project called the GrassGro Teaching Project (1999-2001).

The GrassGro software was adapted from a stand-alone application to one which is now implemented through a central server to provide for the efficient control of the software and to maximise its availability. In this way, access privileges are provided for trained staff and all students enrolled in units using the software. A total of 15 teaching staff have been trained by CSIRO in the use of GrassGro and modules have been developed for teaching in 16 complementary teaching units. The software can now be served out ‘live’ over the Internet, allowing for much broader interest and usage of such Decision Support Tools in education.

Evaluations of student and staff responses have been, and continue to be, carried out. In spite of the relatively limited exposure to this software by the time of their examination, a cohort of senior students in 2000 were found to have a somewhat greater level of understanding of complex ecosystem interactions than their counterparts in 1999, presumably due to their exposure to this project.

Surveys of staff and students were also carried out to determine in what ways the project was succeeding and to identify areas requiring improvement. The first surveys in 2000 found a generally positive response. In response to changes made based on findings in 2000, results in 2001 showed a further improvement in the level of positive response to 26 out of the 29 questions.

Those teachers who had used the software for teaching, reported favourably on its use and especially on its ability to engage students in active learning. Students also reported a substantial level of interest and desire to learn more from the use of simulations. In spite of students’ limited experience with the software to date, the survey results have confirmed the encouragement of problem solving, active learning, engagement, building on prior learning and skill development. The approach has been shown to possess many desirable attributes for enhancing student learning including a capacity to: engage and motivate students, provide realistic and interesting scenarios, be suited to experiential learning, create meaning, and enable self-directed and peer-directed learning.

Aims

Two educational goals were addressed in this project:
1. The software aims to provide a platform for effective teaching of complex biophysical systems which reinforces more basic disciplinary teaching and thereby aims to improve student learning and facilitate improved teaching and collaboration among teachers.
2. To provide a consistent learning tool which facilitates students developing an understanding of principles and the conceptual links between disciplinary units.
Rationale

Lowe (2000) has stated that ‘Much University education in technical areas is fundamentally inadequate ... It is still based on the out-dated model of transmission of a fixed body of knowledge, and so doesn’t prepare graduates for the real world of rapid change’. This project has addressed this need by adopting new and relevant computer aided experiences which are effective and also highly relevant to the workplace.

Historically, a number of applied science and management degrees at UNE (like many other tertiary institutions) have introduced students to basic science and management theory and detailed mechanisms of plant, animal and ecosystem function and management. Often the units in years 1-3 have been taught somewhat in isolation with little explicit recognition of links that exist with other units and discipline areas.

As part of a teaching strategy for the applied degrees (BAg, BRurSc, BNatRes, BEnvSc, BAgEc) this teaching platform was developed to provide links familiar to the students within and between years of the degrees to allow students to develop an understanding of the relationships between the fine detail and the ‘big picture’. Such characteristics are indicative of critical thinkers and of higher level learning.

Prior to this project, individual academics teaching units throughout the School of Rural Science and Natural Resources have used a wide range of computer models and decision support systems to enhance the learning of students. Typically, the models which are available for students to interact with, have been relatively simple and cheap to purchase and therefore are not commercially significant. Also, the use of these computer aids to date has been somewhat ad hoc and has not provided continuity across years or between units. However the present approach facilitates at least three aspects of teaching:

a) **Links between models and teaching.** Parts of the scientific basis of the model are used as examples of principles in appropriate teaching units. By making relevant components of the model available for students as inter-related modules, they can be used to reinforce concepts in units in years 1-3 whilst a familiar platform for subsequent learning is also established.

b) **Improving the computer literacy of graduates.** This is a national priority (DETYA, now DEST, Department of Education, Science and Training); graduates in the natural resources and rural science areas are no exception. The availability of fast computing now provides a teaching medium which enables teachers to present credible evidence of the importance of interactions between a large array of factors associated with the management of natural and managed ecosystems.

c) **Need for understanding of systems.** An understanding and appreciation of the complex interactions among climate, soils, plants, livestock, markets and risk in managed and natural ecosystems is a challenging task to convey to students. This understanding is necessary in today’s world, where decisions about natural resource management and agricultural production are increasingly intertwined and the implications of mismanagement can be loss of sustainable resources or production.

Description of the innovation

The use of a sophisticated computer Decision Support Tool, GrassGro, allows the provision of predictive outcomes (both biological and economic) from agricultural systems in a wide diversity of environments (potentially worldwide). GrassGro is a commercial Decision Support System (DSS), compiled by CSIRO and licensed to Horizon Agriculture Pty Ltd, that has been made available under license to UNE to incorporate into the teaching curriculum.

Figures 1 and 2 below show two screen grabs of an input and an output screen from the GrassGro software.

This software provides an almost infinite range of management choices to explore and is based upon an extensive published scientific knowledge base. The paper by Moore, Donnelly and Freer (1997) describing GrassGro and its antecedent publications directs teachers to a rich source of published literature from which to draw principles and concepts. The use of the program achieves a goal articulated by Biggs (1999) that ‘University teachers should get students to tackle real non-textbook problems, as this is what they are being trained for’.

Improving student learning

The key to the improvement of student understanding by the use of GrassGro is the demonstrable relevance and the credibility of the simulated outcomes brought about by: i) better linkage with theory from lectures (or external teaching material); ii) the availability of the software to allow students to work through detailed scenarios in their own time; and iii) showing detailed outputs from the scenarios (GrassGro currently allows 49 graphical views of various parts of simulated systems).

Figure 1. Location selector in GrassGro enabling selection of numerous sites throughout southern Australia for simulations

Computing details and initialisation files
Control over aspects of running the model are left in the hands of the lecturer who can edit various initialisation (.ini) files to suit their purposes. This has the twin benefits of maximising the flexibility of use by the lecturer and minimising the maintenance requirements on the software provider (i.e. only one version of the software needs to be updated).

In creating a teaching scenario, a lecturer constructs a GrassGro work file and an initialisation file which defines the locality, soil types, pasture species, enterprise, type of simulation, date range, number of paddocks, management, livestock, and costs and prices. Students can develop and save their own unique simulations and build on them over time.

Outcomes
The key achievements of this project include:

• the training of 15 academic staff in the software, and the development of an integrated and linked plan of teaching to ensure complementary approaches by different lecturers;
• the setting up of an NT-server on which a single copy of the GrassGro software has been installed for multiple authorised concurrent users, the writing of initialisation files to enable constraints on the simulation to be applied for particular classroom experiences, and enabling the use of computer laboratories for teaching sessions where at least 20 simulations can be run concurrently;
• the production of a GrassGro Portfolio to provide basic instruction and allow students to construct their own series of GrassGro experiences within a logical, explicit framework;
• specific learning modules have been developed for assisting with aspects of 16 separate units which are either core or elective units for the degrees of Agriculture, Rural Science, Natural Resources, Environmental Science and/or Agricultural and Resource Economics; and
• demonstrable evidence of enhancements to teaching quality and student engagement.

To date, this project has provided a total of some 2000 student experiences in the use of various aspects of the software.

Evaluation
A range of investigative tools, such as questionnaires and interviews (complete survey results and statistical analyses for the examinations conducted are available from the author), have been used with both students and staff to gauge how effective this innovation has been.

Systems understanding by two cohorts of 4th year undergraduates
The changes in student learning that resulted from exposure to the GrassGro modules were assessed by examining two cohorts of 4th year students in 1999 and 2000. These examinations comprised questions relating to the understanding of ecosystem interactions. The results showed a slight but nevertheless significant trend (P=0.086) towards a better understanding from 1999 (average mark 55.2%) to 2000 (average mark 63.8%) which may be attributable to the limited exposure these students had to GrassGro modules (up to 3) by this stage of implementation.

Surveys of students and teachers
Surveys of students and teachers were designed in part to elicit feedback relating to principles of good teaching and learning. For example, some questions were based on Chickering and Ehrmann’s (2000) seven principles...
important in developing technology approaches to teaching and learning whilst others explored Kolb’s (1984) components of experiential learning.

An example of student feedback is given by a cohort of students (mostly mature age) who undertook Agronomy 211 in 2000 and were given one practical experience using GrassGro (similar to the internal students) to demonstrate the differences in adaptation between annual and perennial pasture plants in two different environments. The answers to a survey found that 100% of students found the experience to be either good or very good. Comments included ‘very exciting model’ and ‘would have liked more time to look at a real-life scenario of how model would fit into a farming system’.

A survey was administered to 4th year Agricultural Systems 410 students in October 2000 (who had mostly experienced only 2 to 3 modules of GrassGro by that time) and to 3rd year Agronomy 321 students in October 2001 (who had experienced up to 5 modules in GrassGro). The results showed that the 2001 class ranked 26 out of 29 questions higher than the 2000 class with an overall rise in the mean Likert scale (1-5) from 3.32 to 3.64, a substantial rise within one year. The three questions which had the highest rating related to the great potential students see for this software in their degrees, the fact that it permits exploration of different ways of learning and that it develops cooperation among students.

A survey of staff in late 2000 clearly indicated the great potential that exists for this project to reap substantial teaching/learning benefits. Among the benefits, the project was thought to be generally effective in delivering most of the seven principles of using technology suggested by Chickering and Ehrmann (2000).

There was considerable agreement that the project can meet, or is meeting, the four components of experiential learning suggested by Kolb (1984) of experience, conceptualisation, reflection and active experimentation.

The teachers saw great potential for integration between units and linking theory to practice and there was agreement that the use of the software allows students to build upon prior learning, to improve their skills and knowledge, and increase their understanding of concepts and problem solving.

Portfolio
The student survey conducted during 2000 alerted us to some shortcomings of understanding of the linkages between units. This prompted us to strengthen the integration between GrassGro modules by developing a GrassGro Portfolio which has been made available to each student. This was designed to assist students and teachers in making associations between discipline areas and includes relevant literature sources. The portfolio provides a record and reference point, and a framework for students to see how various disciplines link and build on one another. It supplies much of the ‘mechanics’ of GrassGro software use, freeing lecturer and practical time for the scientific objectives of the unit.

Teaching and learning context
One of the most notable features of the use of this Decision Support Tool in teaching has been the recognition, by students and teachers, that the GrassGro software effectively supports problem based learning. This is important as it is through problem based learning that students get to be actively engaged in the learning process (Biggs and Moore 1993).

As noted by (Ryan 1996) graduates need to be trained to solve ill-structured problems and it is for this reason that a problem based approach is desirable. The access to this packaged ‘knowledge’ in the GrassGro DSS is important in professional disciplines relying on substantive data (in this case the interaction between climate, soils, plants, animals and financial returns).

This project has resulted in increased motivation, integration and focus, depth of learning, student/teacher interaction, and development of critical thinking skills.

Information for other Australian universities regarding this project has been made available through the detailed final report to DETYA which has been sent to all tertiary institutions teaching agricultural and environmental science subjects and via a web portal available at The University of New England (http://www.une.edu.au/dss/).

References
A CD-based courseware package for the teaching and consolidating of geological field skills

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Abstract

This article explores a CD-based courseware package for the teaching and consolidating of geological field skills used for the interpretation of folding sequences in deformed rocks, focusing on examples from Anglesey in North Wales. The article briefly considers the advantages and disadvantages of virtual field work and then discusses the rationale, structure, development and production of the CD-ROM courseware package.

Introduction

A wealth of information relating to Earth’s history, what Holmes (1965) called the ‘pages of earth history’ may be read by geologists from the rocks and minerals of our planet’s crust and mantle. The degree of detail which can be read from the rocks is generally underestimated both by non-scientists and more worryingly, by scientists outside geology. The most powerful interpretation comes from a combination of field-based studies with analytical, computing and remote-sensing techniques based on modern instrumentation and underpinned by the principles of the physical sciences. Field-based studies are therefore absolutely fundamental to the geosciences, as field work supplies raw data for detailed interpretation (e.g. of relative time relations, sedimentary environments, conditions of formation of minerals and ores, etc.) and, on the larger scale, allows the testing of theories proposed as a result of the synthesis of this detailed evidence. Further, these data are potentially invaluable for allowing extrapolation into our planet’s future, something which looks ever more important in the context of possible global environmental change. Professional geologists, trained in field skills amongst others, are required to do this work for society.

An important example of a field technique required by professional geologists is the need to erect relative time scales. One of the situations where this arises occurs when we study rocks from the roots of ancient mountain belts. These rocks contain data about the deformation, metamorphism, magmatism, fluid-rock interactions, exhumation and other processes which were involved in the mountain building events. A powerful technique for determining the number and sequence of deformation events uses the overprinting relationships of minor structures (folds, cleavage/schistosity, crenulation fabrics, lineations, veins, faults) in the deformed rocks (e.g. Cosgrove 1980). Once the sequence is determined, it can be used as a structural time scale (e.g. Johnson 1962) and all of the other information (depths, temperatures, intrusion, fluid migration and ore-forming events, etc.) can be related to it. Erecting such time scales, therefore, constitutes an important skill for professional geologists. This is the subject addressed in the CD-ROM discussed below.

How do we teach this skill?

The technique is best taught in the field and illustrated by the University of Derby field course which takes place in Anglesey and is part of the structural geology module for second year Geology undergraduates. This field trip is long established and has been running for twenty years. Since the mid 1980s it has been coordinated by two of the authors, NFCH and JFWS (latterly APW), who have been responsible for developing the teaching materials and approaches which
form the basis of the CD-ROM package. Some of the teaching is based on our own research (Hudson and Stowell 1997). The field course is immediately preceded by lectures (APW) setting the scene and is followed by mapmaking and other workshops (e.g. fractal analysis). The field course has no look-see element. It is entirely devoted to the development of interpretation and structural-mapping skills. It has a field-based assessment in which candidates produce a field notebook, from observations on a small group of rock exposures, under examination conditions and in a controlled amount of time.

Field teaching is essential for students intending to be professional geologists; however, students’ understanding can be improved by other delivery methods when used in conjunction with field teaching. The CD-ROM package discussed in this paper aims to enhance the learning experience through improvements to pre-field work preparation and field work follow-up studies. The material addressed in the CD-ROM is only a part of the curriculum of field skills taught on the course.

The package will eventually contain three CD-ROMs, which will take three years to develop and test. This article will focus on the first CD-ROM, ‘Geological field skills for structural geologists I: interpretation of deformation sequences from minor structures, a virtual field-instruction package based on the rocks of Anglesey, N. Wales’. Its contents include: recognising and differentiating bedding and cleavage, folds, axial-plane cleavage, cleavage fans, lineations and crenulation fabrics. It also covers identifying overprinting relationships of minor structures in deformed rocks including folded cleavages and lineations, refolded folds and refolded crenulation fabrics. Planned for the future are ‘Geological field skills for structural geologists II: interpretation of major structural geometry from minor structures’ and ‘Geological field skills for structural geologists III: use of the stereographic projection’.

**Advantages and disadvantages of virtual field learning and teaching (VFLT)**

While the pros and cons of VFLT have already been discussed elsewhere (e.g. Stainfield et al. 2000), we consider the main advantages and disadvantages as:

1. improving the efficiency of learning and teaching in the field;
2. relieving pressure on time during field courses through better preparation;
3. relieving pressure on resources by reducing the number of preparatory field days; and
4. informing non-geologists about geological techniques and methods.

It was the first of these that attracted us. The specific advantages for teaching and for informal and formal assessment from our point of view are that VFLT:

1. gives the opportunity for formative practice and testing of field (i.e. close up space) skills; and
2. allows computer-based assessment to be built into the package.

The main disadvantage of VFLT is that development time is quite intensive. The need for planning well in advance cannot be over stressed and the time commitment should be balanced against other competing activities (Research Assessment Exercise (RAE) publications, grant applications and other teaching commitments) before beginning such a project. Some dangers, real or perceived, are that managers might think VFLT replaces field teaching or even replaces staff.

**Rationale and structure of the VFLT CD-ROM package**

A) The preparation section of the CD-ROM deals with background information setting the geological scene for the field course and presents a bibliography. This material was originally addressed in a pre-field course lecture. Figure 1 shows a touch sensitive map of Anglesey from this section which provides a summary of the geology of the rock units by clicking on each of them. More detail can be obtained for Holy Island where most of the field locations occur, through a second larger-scale touch sensitive map.

![Figure 1. Touch sensitive map from the introductory section](image)

B) Teaching and learning structure of main sections

1) Pre-field work sections are based on key field trip locations and address terminology, identification of particular structures, notation systems and the interpretation of overprinting relationships. Figures 2 and 3 are screen grabs showing an annotated teaching exposure and an example field sketch of that exposure from one of the tutorials. These tutorials build up in difficulty, starting with a location where only one deformation event has occurred and ending with three deformations. They can also be used for revision after the field course.

2) Post-field work sections are based on locations which have not been seen on the field trip. Students can access these via hot spots on maps (Figure 4) to try out their skills and receive feedback from the VFLT.
package. Tutorials have text entry responses (Figure 5) and label positioning.

3) The pre-assessment section is formative and is based on an Authorware quiz format using the built-in question styles (Figure 6) which are quick to program. This tests general knowledge of the appropriate techniques and offers feedback.

C) An assessment section of the VFLT package could be accessed by password on the CD-ROM but it is more likely that we will deliver this across the Web for our own students using our well-tested methods (Mackenzie et al., in press – see next edition of PLANET).

Figure 2. Annotated exposure

Figure 3. Example field sketch, from the pre-field course section showing the overprinting relationships of the structures

Figure 4. Map with hot spots giving access to the exposures for the post-field course section of which Figure 5 is an example

Figure 5. Tutorial with facility for text entry

Figure 6. Example question from the pre-assessment quiz

Use of passwords

Pre- and post- field work tutorial sections and the quiz are protected by a series of passwords that must be accumulated by completing the sections. The passwords allow access to progressively more complicated material. The final assessment section can only be accessed by password after the quiz has been completed. The passwords will be generated randomly for each student to
Developing and producing the package

We have been considering a package of this type for some years. Initial attempts (by JFWS and NFCH) to produce a teaching video in the early 1990s were unsuccessful when we discovered that the required image quality could not be achieved. Recently, DMM has encouraged undergraduates to undertake BSc projects that involve an element of tutorial production using Authorware and in 1999 MS elected to carry out such a project on structures in Anglesey, supervised by DMM and NFCH. The photography, the initial CD-ROM design and the primary programming were carried out by MS. The project involved structural geology, photography, tutorial design and programming and resulted in a project report and a CD-ROM. Feedback was sought at this stage from other students. The CD-ROM proved very illuminating because we had a student’s eye view of the learning curve immediately. However, a significant amount of re-ordering, redrawing and reprogramming has been necessary. The following production sequence is based on this experience.

After producing a rationale for the package, as discussed above, the first production step was to carry out individual field work to select the best exposures for demonstrating the structures. It was not possible to do this task whilst simultaneously running the field course. In the event, MS used many of the field trip locations for the teaching sections and chose new ones for the follow-up section. NFCH strongly recommends next writing material in the form of a storyboard as used in the film industry. Each view required is sketched in sequence and given a frame number. The text is written out to the right of each sketch. The designer can then see the whole flow of the tutorial and the material is easily communicated to third parties, such as programmers. Photographs can then be collected specifically for each frame, preferably on an overcast but bright day when the light is diffuse. It is best to have photographs developed whilst you are still in the field as the failure rate can be high. MS began using digital photographs developed whilst you are still in the field as the failure rate can be high. MS began using digital photography but soon found the quality was inadequate and reverted to a SLR camera. Programming is the next step and we recommend Authorware, as it is user friendly and therefore efficient in terms of time. The package can then be tested on students who have already been through the course (third year in this case) to obtain feedback prior to full testing. Adjustments will probably still be required.

We believe that this VFLT package will make a significant contribution to our teaching. The package is also designed to ‘stand alone’ so that it can be used by others. We would be happy to communicate with any potential users and would welcome feedback. It will eventually be available to order through the Centre for Interactive Assessment Development (CIAD) web pages at the University of Derby. We also hope that it might bring some understanding of a small part of field geology to non-geologists through the GEES LTSN subject centre. Finally, we hope that the approach we advocate in this article will be of interest to others, including non-geologists, who are considering producing VFLT packages.

End note

The particular contributions of the authors to the project are indicated in the text by their initials: Smith (MS); Hudson (NFCH); Mackenzie (DMM); Watson (APW); and Gale (JFWS).

References


UniServe Science

Whilst originally set-up through a Federal Government Grant in 1994, UniServe Science is now funded by The University of Sydney through the College of Sciences and Technology, the Faculty of Science and the University Information Technology Committee. UniServe Science caters for Biochemistry, Biology, Chemistry, Computer Science, Geography, Geology, Mathematics & Statistics, Physics and Psychology.

The activities of UniServe Science include:

- collecting information about teaching materials, finding out what is being produced in this country and overseas;
- disseminating all this information, by newsletters and electronic means;
- maintaining a web site which also includes information about discipline-specific teaching resources and links to other relevant sites;
- setting up other exchanges of information by means of the Internet;
- recruiting representatives from every science department in the country in order to establish a nationwide network of direct personal contacts;
- undertaking visits to other institutions and giving talks; and
- holding workshops and seminars.

In addition to these, UniServe Science offers some services to local secondary science educators.

http://science.uniserve.edu.au/

Council for Renewal of Higher Education

The Swedish Council for Renewal of Undergraduate Education was established by the Swedish Parliament on 1st July 1990, and became a permanent National Agency in 1993. Since 1st July 1995 the Council is an integral part of the National Agency for Higher Education. Since October 1999 postgraduate education is included in the Council’s responsibilities which has led to a change of name. The purpose of the Council for Renewal of Higher Education is to promote and support efforts to develop quality and renewal of higher education. The three main activities of the council are:

- to award grants for development activities;
- to collect and disseminate information on planned, current, and completed development activities of a fundamental and innovative nature concerning undergraduate education in Sweden and abroad; and
- to evaluate the development activities the Council has funded.

Some specific objectives of the Council are to:

- support the integration of environmental studies in Sweden undergraduate education;
- support changes in curricula and pedagogy in Engineering and Natural Science programs in order to recruit more female students to these programs; and
- support the use of IT in teacher training.

Currently funded projects include ‘Hypermedia and Communications for Active Learning’, ‘New Forms of Assessment in Mathematics and Computer Science’, ‘Interactive Distance Education in Multimedia’ and ‘Computer Assisted Education in Radiographic Techniques for Dental Students’.

http://www.hgur.se/
http://www.hsv.se/english/

Learning and Teaching Support Network

The LTSN has been established by the UK higher education funding bodies to promote high quality learning and teaching in all subject disciplines in higher education. The network supports the sharing of innovation and good practices in learning and teaching including the use, where appropriate, of communications and information technology.

The network consists of:

- 24 subject centres;
- a Generic Centre (GC) and a Technologies Centre; and
- a program director and coordinator.

Many of the new subject centres build on existing Computers in Teaching Initiative (CTI) Centres and involve learning and teaching support networks created by other funding council initiatives, such as the Fund for the Development of Teaching and Learning (FDTL). The new centres are the main points of contact within subject communities for information and advice on good practices and innovations in learning, teaching and assessment, and will provide support for the many networks which already exist.

The GC provides strategic advice to the sector on generic learning and teaching issues, disseminates good practice in the development and deployment of new methods and new technologies, and acts as a knowledge broker for innovation in learning and teaching.

http://www.ltsn.ac.uk/