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A Student Learning Environment without the Overhead? Reviewing Costs and Benefits of CAL within a Manufacturing Course*

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This paper begins with a brief discussion of the current drivers within higher education and their impact and influence on the learning process. The requirements for an effective infrastructure at the class level are described, with specific links made to the use of computer-aided learninglassessment, effectiveness and efficiency. The paper goes on to describe the authors' experience of using Computer-Aided Learning (CAL) and Computer-Aided Assessment (CAA) in several linked classes over a number of years and to review them in terms of costs, benefits and efficiency.

THE IMPETUS FOR PUTTING STUDENTS IN CONTROL

THE IMPETUS for putting students in control of their learning can be broken down into a number of distinct drivers which encourage the movement away from teacher-led activities to student-centred learning.

At the forefront of these drivers are changes within the overall higher education (HE) environment requiring increased teaching efficiency. The UK HE sector has experienced a period of substantial growth in student numbers. In the academic year 2000–2001, the number of UK students entering HE rose by 9% [1], a trend which the government has indicated will continue. Scotland in particular has already reached the government target of 50% access to HE, well in advance of the 2008 target. This increase parallels a related reduction in funding per student. This has led to recognition both at a national and institutional level for efficiency savings in teaching. Both the Dearing Committee [2] and the McFarlane report [3] recognised a need for teaching efficiency as the student-to-staff ratio increases. This need for efficiency was also explicitly addressed in, and a major driver for, initiatives such as the UK government's Teaching and Learning Technology Programme (TLTP) [4]. Funded for the first three phases to the level of £34 million, TLTP required project bids to focus not only on the increases in effectiveness which the introduction of technology to the learning environment could offer, but also efficiency in the teaching and learning process. Clearly, staff time was and is coming under increasing pressure; moving more control, and responsibility, from the teacher to the learner can lessen this pressure.

In addition to these environmental changes in HE, there has also been an increased focus on learning at the national level. The effectiveness of teaching has been recognised at the UK national level by the Quality Assurance Agency [5], and its predecessor, the Teaching Quality Assessment (TQA). Both schemes demanded sound pedagogy and evidence of effectiveness, monitoring and control. It is not only at the national level that the nature of HE is changing. Within institutions, Johnston [6] highlights an increase in flexibility within degree courses as a common characteristic of many universities.

Beyond the national and institutional drivers for change, there are pedagogical reasons to put students in control of their learning. Learning is inherently a student-based activity, suggesting that teaching should be student-focused rather than the more traditional teacher-focused model [7]. The predominant view of education has moved from teacher-focused education, where the teacher communicates information and knowledge to the student, who absorbs it; to student-focused education, where the student engages in activities which develop their understanding [8]. Some forms of this are known as independent learning, or student-centred learning.

Independent learning is about giving students control of their learning. There is a range of ways in which the student can take more control, ranging from the more common finding of resources to the setting of learning goals [9]. The most common reason for adopting an independent learning approach to education is its encouragement of deeper learning, making it more effective

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[10]. Independent learning also encourages the learner to discover how to 'learn' [11] a crucial skill for lifelong learning. Knowledge of how we learn best is important in order to continue to develop our skills and knowledge.

Developing a lifelong learning approach is recognised generally as an important skill for today's professional and is specifically referenced in the engineering community. The Royal Academy of Engineering [12] recognises the 'need to promote lifelong learning skills'. Further, for an engineering institution to achieve charter status/recognition for its courses, SARTOR requires that 'whatever the discipline or level, an accredited engineering degree course is expected to provide a foundation for a wide range of subsequent study and develop a positive attitude towards lifelong learning' [13].

Thus, assuming more control over learning is a natural progression as a student makes the transition from school to higher education and beyond. A curriculum designed to foster independent learning should explicitly support this process, ensuring that this transition and all stages of the learning process are appropriately supported.

PROVIDING AN INFRASTRUCTURE

In order to put students in control of their learning, it is important that an effective infrastructure is in place. This infrastructure will not only guide the students towards the learning objectives but will also ensure that there are adequate means for maintaining motivation and supporting remedial work. In moving to new approaches to teaching, whether it is in the style of delivery or the technology employed, it is important to ensure that they are properly integrated within the curriculum rather than separate and distracting from the learning process. The infrastructure issue spans the whole spectrum of learning and extends beyond the material delivery to the feedback and assessment areas as well.

Material delivery

There are many mechanisms for delivering learning materials, ranging from traditional lectures, directed reading followed by seminars, to the use of technology. Most courses comprise a combination of these mechanisms, each enriching the learning experience in a different way and supporting specific aspects of the learning process [14].

The use of Computer-Aided Learning (CAL) and on-line learning are now common vehicles for providing learning materials as an alternative to lectures. Rothberg *et al.*'s survey of engineering departments found a variety of forms of CAL adopted into the curriculum [15]. The survey also found that engineering academics have a strong belief that CAL helps engineering education. CAL materials are now available for a wide range of subjects and their adoption is encouraged at a national level through projects such as EASEIT-Eng (part of the UK TLTP projects [16]). The materials typically consist of 'pages' of text and diagrams that learners progress through at their own speed, often taking their own path through the materials rather than in strict sequence. Good-quality CAL materials are distinct from simple 'electronic books' containing animations, sometimes interactive, as well as tests to allow the learner to explore and test newly acquired knowledge. Chu *et al.* found that, on the whole, students are positive when approaching virtual teaching environments [17].

The use of CAL for delivering learning material can lead to an improvement in the material quality, as the learner requires a complete section of material without the lecturer 'filling in the gaps'. Materials will have been developed in such a way that the learner becomes autonomous and the role of the lecturer changes from delivering the essential material to structuring and assisting individuals with specific difficulties.

Material must be presented in the most appropriate form. Using a CAL approach to deliver large volumes of text is inappropriate, as it will not stimulate the interest of the learner. It is, however, well suited to providing animations or simulations that demonstrate concepts that are difficult to convey in a traditional lecture setting (e.g. animating the changes of activity of a manufacturing system over a period of time or the movement of products within it; see Fig. 1). Hsieh and Hsieh showed its application in allowing competency development with rare resources by developing an application to develop the student's skill in using a computer numerical control machine [18]. If the learner is able to interact with a simulation by changing settings and discovering the relationships between those settings and the results, the overall learning experience is significantly enhanced.

Both the introduction to concepts through the use of text and diagrams and the ability to experiment with and extend students' understanding of those concepts through simulation, provides a rich learning environment. In providing such facilities to students, the traditional split between delivering concepts in a lecture and allowing application through labs is blurred. The time between students receiving the concepts and being able to apply them is significantly reduced, thereby allowing immediate testing of their understanding and supporting the learning process more effectively.

There are a number of practicalities for using a CAL approach that must be considered to ensure that the overall learning experience is enhanced. First, and not immediately obvious, is the need for lectures. On introducing CAL, although lectures are often less frequent, they are an important part of providing structure to the material for students, even for those that have used a CAL approach before [19, 20]. Importantly the lectures provide a

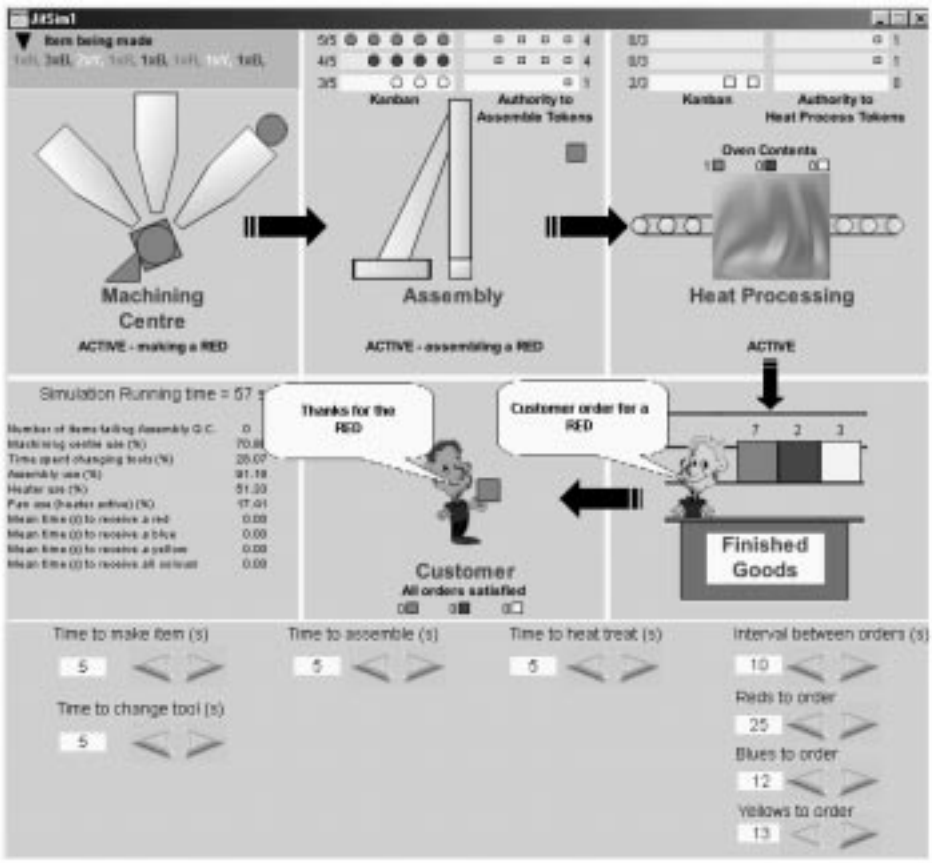

Fig. 1. Example of interactive CAL materials.

means of pacing, either explicitly, through 'milestone' indicators, or implicitly, as the students judge what material they should have covered in the intervening weeks. Lectures are also an efficient means of addressing collective concerns by readdressing areas of the curriculum using different language. Lectures provide a means of presenting more complex concepts that may be difficult to convey using CAL, especially if understanding is enhanced through interaction and discussion.

Also, in introducing CAL to aid the delivery of materials, timetabling and staff presence remain important. Rothberg *et al*. found a higher incidence of unhappy/negative student reaction in uses of CAL which were unscheduled [15]. Timetabling the use of CAL helps students understand the pace at which they should be progressing and thereby make judgements on whether to seek assistance when experiencing difficulties. Timetabling also allows staff to efficiently maintain contact with the students; whilst a reduction in staff time is not necessarily advocated, given the flexible approach students take to learning, it is easy for ad-hoc contact with students across the week to easily exceed nominal allocated time for each class. Staff presence in computer labs is important to provide students with one-to-one or small group explanations of concepts as well as discussions on wider aspects. It is the authors' experience that students tend to use any timetabled study time for specific help rather than concentrated study.

It is important that CAL is effectively integrated into the curriculum. An appropriate balance must be gained. On the one hand, excessive use of CAL to dominate a class can result in a lack of motivation and timely progress by students if they are on a course that predominately uses a lecture-based approach. On the other hand, minimal use of CAL or as a duplication of traditional lectures often results in the material being neglected and not used by the majority of the students, who will seek habit and security in the traditional approach rather than an alternative, potentially deeper, source of learning.

Effective integration can be used to gain, not lose, interaction with staff. If effectively planned, staff do not need to dedicate additional time to students but can devote the time they would previously have spent lecturing. It is important to promote a more student-centred, independent learning approach, so that students have sufficient flexibility to manage their own time. A compromise has to be reached between formal lectures for overall pacing and student study time.

Finally, the materials used need to be appropriate to the learning objectives, but, like textbooks, it is not always possible to find an exact match. Approaches to integrate and tailor existing materials (perhaps obtained commercially) should be used where possible to minimise the time to convert classes to CAL. This can have the advantage of a significant saving in staff time as well as

minimising the need to maintain the materials if upgrades are available. Rothberg *et al.*'s survey reports that the time investment necessary is a major issue for engineering lecturers [15]. The overall development or preparation time of a CAL system is crucial [18].

Whatever materials are used, it is important that students develop knowledge and skills that match the learning objectives and not just skills in the use of the CAL technology. Simple CAL packages can be more effective because, although they may be restricted in their capabilities, they enable students to develop their understanding quickly rather than having an initial program-associated learning curve that will be repeated for each new CAL package used.

Providing feedback for student and staff

Feedback is a crucial element of successful learning. Students require feedback to test their current understanding and to elicit further knowledge to extend that understanding. Feedback features in most theories of learning. Both the Kolb experiential learning cycle [21], which is often used to underpin curriculum design and in education literature (Fig. 2), and Llaurillard's conversational framework [14], a framework to place educational resources to directly support aspects of the learning process, explicitly outline the importance of feedback to the learner. Feedback from, or interaction with, the lecturer can be designed into the curriculum in a number of ways.

Tutorials are traditionally viewed as an opportunity for one-to-one interaction with the lecturer. The tutorial supports the testing stage of the Kolb cycle but also provides feedback in other forms. Tutorial exercises provide an important form of self-assessment, allowing students to test their understanding and receive feedback to help develop understanding further, moving round the learning cycle. It also provides an important function in motivating and encouraging the student, allowing for advanced direction and an indication of the standards expected for examinations. Additionally, meeting with other students in the class develops a peer group of learners with whom to share learning and to give an indication of relative progress [22]. This tutorial interaction can be even more important when the class involves CAL, as lectures are often removed from the course, cutting down on the opportunity for interaction of this kind.

Self-assessment exercises can encourage learner independence: learners can check their progress, consolidate learning and direct further knowledge acquisition, thus reducing the time taken to move round the learning cycle. Again, this is particularly important in a CAL environment, as it can provide much-needed reassurance over progress—anxiety over progress is often found with new learning methods. Hypertext systems, in particular, can often leave the learner without a sense of progress or location in the material, feeling that they are 'browsing' rather than learning, so an objective measure of progress is welcome [17, 22].

As with the student, feedback is also an important process for staff. Class feedback is widely recognised as a valuable element of formative class evaluation—a requirement of continued curriculum development. Unfortunately, the trade-off of energy to benefit remains. Informal discussion with students is valuable and requires little time and effort. While useful for monitoring a course, curriculum development requires more representative and formal feedback. 'How effective is the addition of this new resource?' is the question at the forefront of the lecturer's mind.

There is a range of evaluation tools available to the lecturer in this position. The LTDI evaluation cookbook [23], a helpful resource specifically aimed at lecturers in this position, lists 16 formal methods and rates the amount of time required for their preparation, to conduct them and for subsequent analysis (Table 1).

Questionnaires requiring moderate or low time investment are the most popular method for class evaluation. The feedback is both representative of the class and can be very specific in addressing the areas of particular interest. Less formal methods, including spot tests or pop quizzes, are valuable in

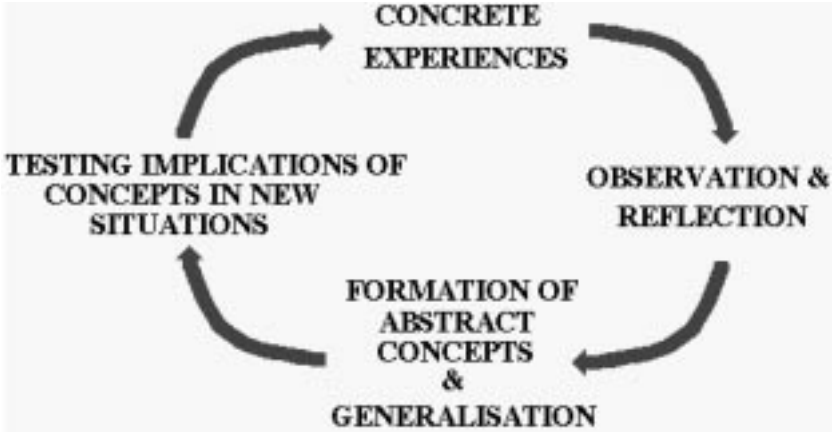

Fig. 2. Kolb experiential learning cycle.

Table 1. Extract from the LTDI evaluation cookbook

Method	Preparation	Conduct	Analysis
Checklists	Low–mod	Low	Low
Concept maps	Low	Low	Low
Confidence logs	Low–mod	Low	Mod
Cost-effectiveness	Mod–high	None	Mod–high
Designing experiments	High	Low–mod	Low
Ethnography	Low	High	High
Focus groups	Low	Mod	Low–mod
Interviews	Mod–high	High	Mod–high
Nominal group techniques	Low	Low	Low
Pre- and post-testing	High	Mod–high	Mod
Questionnaires	Mod	Low	Mod
Resource questionnaires	Low	Low	Mod
Split-screen video	Mod	Mod	Mod
Supplemental observation	Low–mod	Mod	Mod
System log data	Mod–high	Low	Mod
Trials	Mod	Mod	Mod

indicating a class's development academically and can be used repeatedly to chart progress. An evaluation method that addresses some of the problems mentioned is that of confidence logs. A confidence log consists of a number of statements, each relating to areas of the class learning objectives. Students are asked (often anonymously) to rate their confidence in relation to each of the statements (see Fig. 3 below). Students' estimations of their abilities in particular areas are often very accurate [24]. Repeated use of confidence logs over a class allows the student's perception of their learning to be charted over the course without the negative aspects of testing. Although this is a perception rather than a more objective measure of learning, the results are correlated.

A log of the class's confidence in each of the main skills and knowledge objectives of the class will highlight prior knowledge and help to link specific activities to advances in student confidence, thus uncovering areas of weakness. For example, it is often the timing of assignments rather than the lectures or tutorials that has the most significant impact on learning. This can be information gathered with a relatively cheap investment of time.

It is sometimes possible to link individual logs but removing the anonymity of the student is not recommended, as it seriously compromises the validity of the method. Other methods for pairing can be used, such as asking the student to write a code name that is the same on each of their logs. Paired logs allow the teacher to chart not the level of confidence but changes in confidence, which can be particularly useful when relating the logs to specific learning activities.

Assessment

CAL can also result in changes to the class infrastructure in the area of assessment. Assessment is a crucial influence on student motivation. Computer-Aided Assessment (CAA), both formative and summative, offers substantial opportunity for efficiency gains in terms of staff time. Marking assessments can involve a considerable time investment and, in the case of summative assessment, often does not provide feedback to the student's learning process beyond a mark. CAA can therefore benefit the lecturer by reducing time commitment without an associated negative impact on the students learning. As a result, the area of CAA can offer the greatest opportunity for efficiency gains

Topic	very confident	confident	some confidence	little confidence	no confidence
Understanding of the use and application of simulation					
Understanding of the concepts of event, activities & queues					
Ability to describe timing control mechanism of a simulation executive					
Ability to explain deterministic and stochastic modelling					
Knowledge of the principles and methods of sampling					
Ability to describe how to ensure validity of models					
Ability to describe the principle types of simulation package					
Understanding of the procedure for selecting a package					
Ability to design and implement a spreadsheet model					
Ability to describe the main stages of a simulation project					
Ability to carry out the key stages of simulation project					
Knowledge of some trends in simulation techniques					

Fig. 3. Example of a confidence log.

within the computer-aided education field but often does not receive the same attention as the production of CAL materials. A key barrier to its use is that CAA is often considered only to be suitable for multiple-choice questions and testing memory rather than understanding [25]. This is a misconception. With careful design, CAA, and indeed the multiple-choice format, can test student understanding and ability in depth [26]. Issues such as security of test material and reliability of marking, both areas of concern, can be easily addressed by basic precautions and thoughtful design.

This first section of the paper has examined some of the current drivers in education and their relationship to the level of control that the learner has. The requirements for an effective infrastructure have been outlined and issues of possible efficiency in the teaching and learning process have been discussed, linking to the development and use of CAL within this context. The paper now describes and reviews a specific use of CAL in practice, explicitly addressing these issues.

CASE STUDY IMPLEMENTATION IN MANUFACTURING EDUCATION

This section reports on an initiative to introduce learning and assessment technologies in several classes across three years of a manufacturing degree. Initially, students were simply made aware of this additional resource to complement existing lectures, books, papers and notes. However, the use of the materials was poor, if not non-existent, due to the lack of incentives to use them and ineffective integration. Classes were then reorganised to provide better integration and encourage a more flexible learning approach in students. A number of features of best practice [27] were used. The new structure used an integrated combination of lectures, Computer-Aided Learning (CAL) and Computer-Aided Assessment (CAA). The changes aimed to encourage a deeper form of student learning with a more flexible approach.

Using a combination of commercial modules and modules developed in-house, existing lectures were replaced by CAL materials. In second and third year operations management classes, this amounted to about 25% of the curriculum. In a fourth-year simulation class, the level of CAL started at 50% and subsequently rose to 75%. The method of integration of the material was the same for each class.

To match the phases of material delivery, formative assessment and summative assessment, a number of tools were used in the classes. First, a CAL package (LearnOR) was used to provide and produce the basic material, followed by an assessment package (Question Mark) for students to self-assess their progress and, finally, an assessment environment (CVU) was used, in some cases, for formal assessment. Each of these tools will now be described in turn.

Overview of the LearnOR package

LearnOR is a product of the MENTOR project, a UK-funded TLTP programme which was set up to develop CAL materials specifically for the operational research area [20]. The project developed a learning system, LearnOR, and a number of learning modules, from inventory control to simulation modelling. The LearnOR system is capable of providing both a learning environment for students to access the modules (see Fig. 4) as well as an authoring environment for staff to develop these modules.

The modules included text, diagrams, animations and links to test banks (see below). Continuous text is too easy to enter into any CAL package and self-discipline has to be exercised to ensure that a balance of diagrams, animations and interactivity is built in to maintain interest. Text is often cited as being difficult to read from the screen and fails to exploit the features of software that could enhance the learning experience, such as interaction and experimentation. Animations were used to address concepts that are difficult to demonstrate in traditional lectures, such as those

Fig. 4. An example of the LearnOR package.

involving complex interaction or a sequence of events occurring over time. These animations could be played repeatedly and avoided the pitfalls of material that simply required repetitive mouse clicking to progress [28].

Broadly speaking, there are two types of learners: one that studies in a linear, structured manner through materials, described by Pask as 'serialist'; and the other who is able to jump between areas of material and piece together this material into a whole, Pask's 'holists' [29]. The environment is able to support both approaches. Firstly, the materials are assembled as pages in a linear fashion and the learner moves from one page to the next using progress buttons. Secondly, hyperlinks enable the learner to jump between related concepts in a path that was not pre-planned by the developer of the materials.

Tracking progress through the learning materials is important to both the student and the lecturer. The LearnOR environment is able to save the history of progress through the materials, the last position, as well as to identify areas of the material that they have not yet seen. Through the university network, centralised records can be kept of students' progress so that staff can monitor the collective use of the materials and therefore control a large, often virtual group of learners.

The LearnOR environment and modules were highly portable. Home installation of the software required minimum skill and the simplicity of the software meant that it was able to run on computers with any version of the Windows operating system. This served to reinforce to the student that the challenge was in studying and understanding the materials rather than accessing and navigating the program.

Developing the LearnOR materials

The task of developing the materials for these classes was a combination of integrating existing material and developing new material. New modules were created for the operations management classes as well as a small module to complement the MENTOR module for the simulation class.

The authoring system was easy to learn and, once mastered, a module replacing one hour of teaching took approximately an intensive day to create, comparing favourably with typically quoted times to produce CAL-type materials [18, 30]. Moderate levels of IT proficiency were required to develop the materials. Whilst programming was not required, skill was needed to manipulate graphics and create hyperlinks. Most of the time taken was spent structuring the material and creating animations and interactivity. The text was the easiest element to enter and restraint had to be exercised to ensure that this did not dominate. Significant efforts were made to discourage repetitive mouse clicking (or 'page turning') by a superficial user and encourage deeper learning using interactivity by posing questions, incorporating simple tests and providing animations of concepts. To reduce development time and hardware requirements, video and sound were deliberately avoided.

In the absence of a standard national curriculum within higher education, the likelihood of finding off-the-shelf materials to exactly suit a specific class or module is very low. The temptation to develop materials from scratch to meet the needs of a class is consequently very high. The approach taken where possible, however, was to develop additional materials to integrate with the off-the-shelf materials, thus minimising the development effort.

Using the LearnOR materials

The LearnOR system had a minimal number of navigational controls. Initially, training sessions were organised, but it was found that many moved from training to study mode within about ten minutes and so these sessions were not continued in future years.

The materials were used in conjunction with formal lectures. This approach gave the students variety in the delivery of material, a pacing across the semester that they would not implicitly get from using the CAL materials alone and a means of staff keeping in regular contact with the students.

For the lectures that were replaced by the use of CAL, computer rooms were booked in their place. Staff would be on patrol to assist students. Although this did not reduce the formal contact time with students, it did permit individual help that would have previously occurred outside of this time. Students would use the university computer rooms at these scheduled times as well as on an ad-hoc basis. Many students, however, find that these rooms did not offer the ideal environment for dedicated study. As the weeks progressed, students changed to using the timetabled sessions for one-to-one help and spending 'quality' time on the materials elsewhere, often in the evenings at home.

Question Mark

Each LearnOR module covered a particular aspect of manufacturing and had an associated Question Mark test. The tests enabled students to carry out self-assessment of the module, thus providing fast feedback (and therefore motivation and confidence to study further) and supporting movement through the learning cycle.

Question Mark (QM) [31] is a CAA package that enables tests to be quickly authored for student use. It supports a range of question types, from multiple-choice to text-matching, and allows a variety of modes of use to restrict whether students can return to previous questions or whether the tests are timed. The software is able to automatically mark the students' responses, including the text responses, by matching against expected words used as answers. Diagrams and

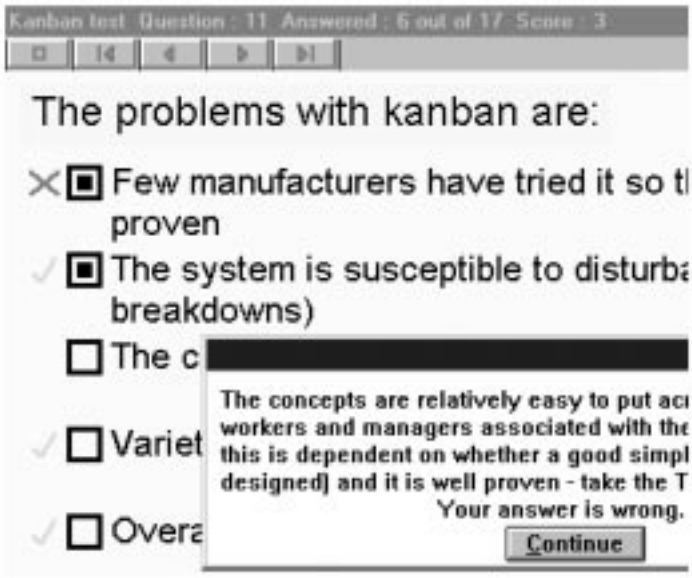

Fig. 5. Example of Question Mark test.

pictures can be included to enhance the test appearance and can be used within the actual response (e.g. a question requiring the student to identify a position within a diagram). No training was given in the use of the tests and students appeared to use them with ease.

It was possible to use the assessment package to provide feedback to the user in the case of an incorrect response. Whilst the questions are quick to input, providing feedback slows the development of the tests considerably. Despite this burden, the time spent can be considered worthwhile, as it provides a means of enhancing the learning experience.

No manufacturing or operations management specific tests were available, hence these had to be developed. An example of the material created is shown in Fig. 5. The time spent developing each test bank was small compared to that of the learning module, even when the provision of feedback on answers is taken into account.

Like the LearnOR modules, the test banks were easy to distribute and students could take them home. Links were provided in the LearnOR modules to the tests, so that students were encouraged to use the tests immediately, although they could also be used as a standalone for testing knowledge some time after using the learning materials.

Due to the distributed mode of student study, the self-assessment results were not available to staff. This was not considered detrimental to the running of the class, as students were more willing to use the tests for their learning when they felt they were not being monitored by staff. Interestingly, it has been observed in the university that more able students will often deliberately select the wrong answers to obtain more feedback. This would suggest that any results collected would therefore not be representative.

CVU

The Clyde Virtual University (CVU) [32] is a collaboration between four universities based in the west of Scotland using the World Wide Web to both deliver study materials and provide a means of assessment. Here the CVU was used in a simulation modelling class as an element of summative assessment (along with coursework). Although this is not part of the learning cycle, it directly affects student motivation and the direction of study. Two tests were developed that, combined, contributed to 25% of the overall class mark. The first test was an incentive for the students to study and grasp the basic materials early on, whilst the second test was used at the end to gauge overall learning.

Students sat a computer-based test containing questions in much the same style as the Question Mark formative self-assessment modules. Once a student had submitted the test, the multiple-choice and multiple-response questions were automatically marked, whilst the free text responses were marked by staff. The electronic nature of the test allowed question-by-question rather than student-by-student marking, which helped ensure consistency. The testing process was efficient, but care was required to keep the test paper secure [27].

Lectures and tutorials

Lectures were still used and seen as an important part of the students' overall learning experience; however, the original style and number of lectures was changed significantly. Whilst it would have been easy for staff to replace all lectures with CAL, a number of dangers observed from other implementations [19, 20] suggested that a more balanced approach was appropriate. Traditional lecturing was used to structure and motivate students as before but was interspersed with the use of CAL. Here, 'material delivery' lectures were replaced

with 'overview' lectures, lecturers patrolling labs offering one-to-one support and formal tutorials to aid the application of the materials. Students would use the CAL material to gain an understanding of the basic concepts and the formal tutorials would enable the lecturers to put this into context through case studies.

The self-study approach of CAL can allow students to put off learning in favour of other study. Lecture time was used to set the pace, guide progress, give an indication of the depth of learning expected and give reassurance to those not familiar with this type of learning.

Although this approach resulted in fewer lectures, the contact time for lecturers did not diminish, as there was the need to patrol labs at timetabled hours to provide one-to-one assistance. From the student perspective, although formal contact time fell, there was a greater opportunity to gain individual or small group assistance.

The use of web and e-mail was extensive. The web provided a central resource for the students to access materials available locally and globally. Latterly, a significant part of the LearnOR material has been moved to the web to provide a single access point to all resources. E-mail was an important mechanism for students to highlight hurdles in the material as well as a way of expressing their new understanding. This was particularly important where students preferred to study using CAL at non-timetabled hours. In most cases, concerns were noted and addressed in the next formal lecture. It was noted anecdotally that a greater amount of feedback was given as a result of students' detailed study in labs compared with traditionally structured classes.

Notes and note-taking

Students were expected to take notes whilst studying, to help understanding as well as to provide a later revision aid. Printed notes were provided containing key diagrams and text but were largely blank for students to annotate. These 'template' notes proved to be an important element of integrating the study materials. Students were able to better judge the scope and detail of study required as well as to view the different CAL packages used for the classes as one integrated set of materials. Thus, off-the-shelf materials as well as in-house authored materials were presented as one common package rather than a disparate set that students had to form links between.

It is also worth noting that the LearnOR materials could not be printed and the cut-and-paste facility was very limited. This limitation imposed by the developers was to encourage immediate understanding rather than printing out materials for later study. This would have eroded the flexibility of learning paths and lost the interactive elements. The 'template' notes therefore acted as a balance for the students between a full set of printed notes and laborious copying of diagrams.

Staff evaluation

Two forms of evaluation were used during the delivery of these classes, namely confidence logs and final questionnaires. The evaluation mechanisms are independent of the method of delivering the materials; however, the confidence logs [23] were particularly useful in tracking student progress against expected pace.

Students were asked to assess periodically their confidence against the class learning objectives (an example is shown in Fig. 3). The aim is not to track individuals but the group as a whole and this provided an efficient means of judging perceived progress.

Even without receiving the results of the logs (see Fig. 6), the students were regularly asked to assess their performance against the learning objectives and therefore were encouraged to focus on the objectives rather than the activities. This would in turn encourage them to express their problems with the material they were studying in the context of the learning objectives. Staff used

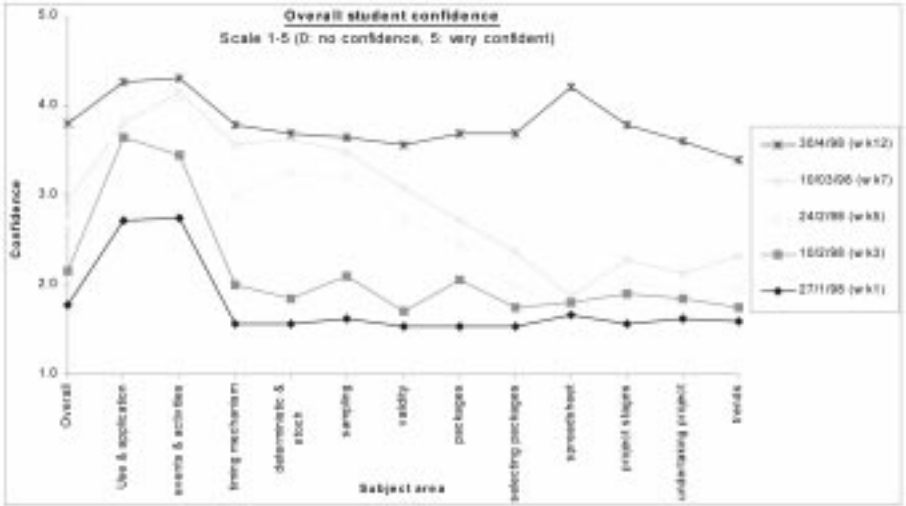

Fig. 6. Example of the results from confidence logs.

the results to prompt remedial work and therefore assisted in reinforcing the feedback part of the learning cycle.

More formal feedback from students was gained from an anonymous questionnaire at the end of the module. The questionnaire was broad and gained feedback on all aspects of the class delivery, including subject matter, media used and staff performance. Feedback from the questionnaire was used locally to improve the classes as well as for the department's annual review of its teaching portfolio.

EVALUATION

Using questionnaires and confidence logs, the benefits and acceptability of CAL were measured. This section details the outcome of the use of CAL, in particular drawing on reports from the final year modelling and simulation class in which the level of CAL use was highest.

Independent progress

About half the students stated that the use of the confidence logs was helpful for their motivation. Anecdotal reasons for this were that being monitored reminded them of the progress they needed to make. It suggests that students needed incentives to regularly use CAL, more so than regularly attending lectures, even those lectures perceived to be 'information giving' and lacking interaction!

Few students stated that the use of CAL encouraged progress more than lectures, but a very high number felt that CAL did help them learn. This suggests that CAL had a positive influence on learning but could not be used in isolation. The vast majority of students felt that the pace and mix of elements was about right, suggesting that the use of CAL was accepted and that the level was judged to be appropriate.

Most students took notes from the CAL material even though access to it was not time limited and many students returned to the CAL for revision purposes to revisit areas they felt unsure of.

When CAL was used varied enormously, with a third using the material at any time, a third using it only during the day (including weekends) and the remainder using it only during the evening or only during weekdays. Around half used the materials from home. Anecdotally, the approach allowed motivated students of all abilities to progress; however, its flexibility allowed some students to delay their study and leave little time for preparation for assessments. This reflects on the students' time management rather than on the CAL materials or the structure of the class.

Academic performance

Students showed good levels of motivation, as indicated by confidence log return rates, results from questionnaires and overall attainment. Students' performance will naturally vary from year to year, and in the year of introduction of CAL materials the standard of achievement rose. Whilst this could be attributed to either natural variation or a positive influence of the CAL approach, it can be claimed that the use of CAL did not result in deterioration in performance which could have resulted from poor study materials or lack of motivation. Since the initial introduction of CAL five years ago, the level of performance has settled at its original level.

Use of CAL 'about right'

Across all classes, the students consistently judged the level of integration to be appropriate, despite variations in the level of CAL use. For those suggesting a change in the level of use of CAL, more wanted an increase, citing the control of the pace of learning as the main benefit. Interestingly, no one used the CAL material in isolation, with students using CAL to replace lectures, papers or books. It was not investigated whether the level of CAL would always be appropriate if integrated well or whether the level was appropriate to the year of study, with students in earlier years needing greater reassurance through the comfort of 'traditional' lectures.

As the students covered a subject area for a particular learning objective, the logs showed that their confidence rose dramatically. Interestingly, however, so did the general level of confidence and there were also slight rises in confidence about subjects they, according to the timetable, had yet to study. This could indicate that the overall approach taken enabled the keen students to progress and study materials earlier. There were differences between year groups, with those in the earlier years requiring more incentives to study at their own pace and less prepared to manage their own time.

In some classes there were a significant number of overseas students for whom English was not their first language. This was recorded in the confidence log responses to assess whether any particular groups of students were being disadvantaged. Over a period of time, little difference in the groups was discernable. With the previous more traditional lecture approach to delivering the material, it was noted that overseas students had more difficulty in class due to speed of delivery or accent, demonstrating a benefit of the use of CAL for students whose first language is not English.

For the CAL material itself, some students cited deficiencies relating to the content, in particular the need for more interaction to maintain interest. In developing the CAL materials, the relative ease of adding text and static diagrams was noted, whereas time and sometimes more skill were required to provide animations and interaction.

REVIEW

This section reviews the use of learning technology in the manufacturing classes to bring out key lessons of its integration into the degree courses. The review first examines the benefits, then the associated costs, and finally assesses the efficiency and effectiveness of the approach used.

Review of benefits

The underlying aim of the approach was to provide a student-centred approach to learning. Incorporated into this was the need to promote lifelong learning [12] and benefit from greater student control of learning, including deeper learning [10]. In reviewing the classes, there was clear evidence that students accepted the flexibility of the approach without detriment to their performance. The surveys of students also indicated that they were studying at a time that best suited them.

The learning technology used provided the students with quality study materials. The materials were easily accessible and self-explanatory. However, the need for effective integration of these materials into the classes was clearly demonstrated. Early approaches of providing the materials as an optional extra resulted in little or no take-up. However, later approaches with better integration of the materials into the classes resulted in very high use. It is worth noting that the change here was in the way the materials were used rather than in developing the materials further. Integration allowed students to study effectively and move seamlessly between study materials, thereby concentrating on the materials not the format.

Lectures were still needed for structuring and the provision of template notes were also very important to support efficient but effective study. The students were given a balance of structure through lectures and one-to-one support to help with individual difficulties. In integrating the materials, there was more consideration given to the learning cycle. For example, there was greater awareness of where things could go wrong and mechanisms (such as the confidence logs) were put in place to monitor students and offer them feedback. This approach supports the different stages of Llaurillard's conversational framework [14].

Review of cost

In introducing this learning technology, emphasis was placed on the integration of existing materials rather than on the creation of new materials. Despite this, there were still financial and staff time costs associated with this approach.

Time was spent developing materials, but it was not considered that high when compared with commonly quoted figures. The use of simple but effective tools (e.g. LearnOR) had a significant impact on minimising this. In developing the materials, relatively little time was spent converting existing material (e.g. lecture notes); most time was spent developing new ways to explain concepts (other than verbal explanations), such as animations, which would have enhanced traditional lectures anyway.

Whilst there was an initial investment in developing the class, once the class was implemented it was a change in the balance of staff time rather than the total time that was most notable. Less time was dedicated to formal large group contact and more time was spent discussing and explaining concepts with individuals or small groups. The effect was that students received more focused help but without an increase in staff time dedicated to the class. The problem, however, with such a flexible approach is that there is a danger that more staff time could be spent, on providing support at different times of the week rather than at a fixed time. A balance between the flexibility of student self-study and the flexibility of interaction with staff needs to be considered carefully. Overall, the aim has been to rebalance time to make pedagogical gains rather than find means of significantly reducing time spent on a particular class.

Issues relating to cost reach beyond the department level to the student and university levels. The move to CAL puts additional strain on university computing resources through increased PC laboratory bookings and increased computer-based private study by students. With the rise in PC ownership, there is a transition from thinking that using a PC at home is of benefit to the expectation that students will be able to use a PC at home, and the use of CAL aims to exploit this rather than merely benefit from this additional resource. This has implications for the costs for the student as well as on the staff in other classes as the expectations of study flexibility and material quality from students rise.

The use of questionnaires and anecdotal evidence showed that the change in the style of the class from lecture-based and lecturer-centred to student-centred learning was beneficial to the students in that it provided them with a stimulating and flexible approach but without additional staff time beyond the initial investment. However, the question remains as to whether the approach taken can be properly accounted for compared to the previous traditional approach. Whilst the cash outlay can be budgeted for and tracked (e.g. buying CAL materials), the staff time is traditionally not monitored (e.g. the investment in creating in-house materials). Taking this further, it is superficially cheaper to create materials in-house rather than buying materials in. The lack of a project management approach in universities prevents a true comparison. Certainly, the initial investment in CAL required a large amount of staff time to source, create and integrate learning and assessment materials. Some of this was one-off and some involved ongoing maintenance of materials and gradually converting them, in the same way that traditional lecture materials would be periodically reviewed and updated.

Review of efficiency and effectiveness

Whilst it is difficult to detect changes in the performance in classes prior to the introduction of CAL, with there is confidence that performance has not deteriorated in subsequent years. Results showed slightly better levels of performance after the introduction; however, this could simply be down to natural variation between years or the Hawthorne effect. Formal and anecdotal evidence also showed that students enjoyed the class and consistently reported the level of CAL to be 'about right', even though levels of CAL differed between classes. A key part of accepting the flexibility of this approach was effective integration.

Sourcing materials is an issue and good integration allows commercially obtained and in-house authored materials to be mixed. There is, however, a lack of commercially available materials, especially for assessment. Overall, it was felt there was an increase in quality through better structured materials (enhanced by the use of interaction and animations), more flexible access to them and provision of self-assessment. This enhances the previous lecture approach by incorporating a greater part of Kolb's experiential learning cycle, allowing enhanced exploration and consolidation.

Creating simple CAL materials is quick and maintenance is easy, but care must be exercised not to lose sight of the overall aim. Although interaction is more time-consuming to develop than text, it is essential to enable students to explore and develop deep understanding. Additionally, students frequently cited large volumes of text as difficult to read from the PC screen. Most importantly, students did not rely on CAL as the sole source of learning and combined it with other written materials to complete the assessments.

Compared with the earlier, more traditional, approach used to deliver these classes, a greater amount of feedback was included without any significant increase in overall time spent on the class. The feedback took a number of forms. The first was feedback through self-assessment test banks to reinforce the need to move around the Kolb/Lewian learning cycle. Secondly, feedback to staff on material use was monitored very early on, but the remote learning approach made collection of data unreliable. Thirdly, feedback in the form of student confidence logs was more meaningful, allowing staff to monitor perceived learning rather than progress or time spent on the materials. Tracking of progress was paper-based and so did require some collation time (hence staff cost) for the results of the confidence logs, but the benefits outweighed the time investment. Monitoring allowed for early detection of problems and checking whether the speed of learning demanded by class schedules was appropriate. Tracking of students was group based and, like many other forms of teaching, offers no individual tracking. This was deliberate to ensure good questionnaire response rates, but it is acknowledged that this does not capitalise on the use of technology to identify students at risk.

Whilst the term 'CAL' has been used throughout, much of the material has been converted to web-based format since its first introduction. This has allowed more flexible on-line provision of the materials. CDs are still made available to students who want to take copies of the web-based materials home without the need for Internet access. Interestingly, these CDs are still in high demand, indicating that it is the portability of the materials rather than the web-based, on-line access that is important to students. The insights arising from the work on introducing CAL materials here is therefore just as applicable to web-based provision.

The case study has demonstrated the benefits at class level. At degree course level or institutional level, there are also benefits to be gained. Again, it is difficult to assess the cost versus the benefit. With the modelling class, there are now examples of students studying the class overseas, following the same material and taking the same assessments. Other classes in department are being converted to a flexible approach and there is one possibility of a class being delivered to students studying for a degree at another university. Whilst there may be immediate local benefits by offering flexibility to current students, there may be wider benefits for offering classes or whole degrees remotely.

This review section has highlighted key lessons from the introduction of a flexible learning approach in a number of classes of a manufacturing course. The section has brought together issues that have arisen from the case study and related them to the introductory theory. The section provides valuable insight to those considering introducing a more flexible approach to learning based on the use of Computer-Aided Learning and Assessment packages.

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