Int. J. Engng Ed. Vol. 13, No. 1, pp. 64–71, 1997
Printed in Great Britain.

0949-149X/91 $3.00 + 0.00

A Computer-Based Teaching System for Electronic Design Education

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The Electronic Design Education Consortium (EDEC) is dedicated to the production of computer-based teaching and learning material to support the education of electronic engineers and computer scientists. It is one of the projects being funded under the Teaching and Learning Technology Programme (TLTP), a major initiative of the UK Higher Education Funding Councils aimed at making teaching and learning more productive and efficient by harnessing modern technology. This paper begins with a brief overview of the development of computer-based teaching and learning in the UK. The aims and objectives of the TLTP are then set out in sufficient detail to understand the context in which the EDEC project is operating. This is followed by an account of the methods being used by EDEC to achieve its stated goals of producing 160 h of courseware during the 3-year duration of the project.

INTRODUCTION

THE IDEA of using computers in teaching is hardly new. Almost since the dawn of computing efforts have been made to apply this technology to the education process, and early attempts in the USA and elsewhere have been written into the folklore of computer-based teaching and learning.

In Britain responsibility for the development of IT policy in the universities was placed in the hands of the Computer Board for Universities and Research Councils (usually referred to just as the Computer Board) when it was founded in 19676. Originally the Computer Board saw its remit as providing computers to support *research* with no mention made of teaching, although this oversight was later recognized by Barnard [1] and rectified. Following the publication of the Barnard Report, the first initiative aimed at developing the use of computers in education was launched in the shape of the National Development Programme for Computer Assisted Learning (NDPCAL) [2]. This 5-year research and development programme aimed to integrate the use of computers into all branches of education including schools, colleges, and industrial training establishments as well as higher education. In many ways the timing of the programme could hardly have been worse—it ended just as the first microcomputers were being launched onto the market.

The idea of computer literacy being an essential requirement for all students irrespective of their subject discipline was slowly gathering momentum. There was still some confusion, however, over the precise form that this literacy should take and how it should be delivered. In 1983 the Computer Board commissioned a review of computing facilities for teaching in universities which led to the publication of the Nelson Report [3]. One of the fundamental recommendations of the Nelson Report was the setting of a target of one computer workstation per five undergraduate students by 1990. Another survey of the provision of computing facilities for teaching was carried out by the Inter-University Committee on Computing (IUCC) in 1991. This reached the disturbing conclusion that out of 44 institutions which responded to the survey, over half (25) had failed even to achieve a 1:10 ratio—halfway to the Nelson target set for 1990—while only three institutions had actually met or exceeded the target [4].

A beneficial outcome of the Nelson report was the launching of the Computers in Teaching Initiative (CTI) in 1985 with funding provided by the Computer Board and the UGC (University Grants Committee—later to be renamed the Universities Funding Council or UFC). The CTI's aims were to:

- evaluate the educational potential of IT in university teaching;
- raise the level of awareness of IT among academics and students;
- promote the development of computer-mediated training and learning.

The first phase provided £9.5 m. funding for over 100 projects during the 4-year period 1985–

* Accepted 1 July 1996.

89, while a second phase saw the establishment of some 20 CTI Centres, each of which was focused on a specific discipline [5]. The CTI Centres have been charged with the task of 'enhancing the quality of learning and increasing the effectiveness of teaching in all subjects within the UK university sector through the application of information technology'. They accomplish this by publishing newsletter and directories containing information on educationally useful software in specific disciplines and running activities such as courses and workshops. The CTI Centres have recently entered a third phase which will enable these activities to continue while some of the later developments to be described below begin to bear fruit.

The 1990s have already witnessed the introduction of two major IT initiatives in the UK university sector. The first of these is the Information Technology Training Initiative (ITTI), which commenced in 1990 and aims to improve the availability of IT training materials to assist computer centres in dealing with their IT support role [6]. The second and by far the most significant is the Teaching and Learning Technology Programme (TLTP) and this is described in more detail in the following section.

THE TEACHING AND LEARNING TECHNOLOGY PROGRAMME

The declared aim of the TLTP [7] is to make teaching and learning more productive and efficient by harnessing modern technology. Whereas improving the quality of both teaching provision and the learning experience of the student can be viewed as one of the objectives of TLTP, it is fundamentally based on the bold assumption that cost savings can be made in the way that university education is provided. It therefore seeks to find new methods of exploiting IT to teach larger numbers of students with no increase in staff numbers.

The programme was launched in August 1992 with the announcement of 43 projects that were to be funded for periods of up to 3 years. The total amount of funding dedicated to the programme in its first year was £7.5 m. with the expectation that similar sums would be allocated in years 2 and 3. A second phase of TLTP funding was announced in August 1993 to support a further 33 projects at an estimated annual cost of around £3.75 m. The phase 2 TLTP projects will also run for up to 3 years, thus bringing the total projected cost of the programme to be somewhere in the region of £33 m. To this should be added the cost of the academic staff time that is being devoted to the project—and experience to date has shown this to be not insubstantial. It is probably realistic, therefore, to think in terms of the TLT programme representing a £40 m. investment in the application of multimedia in higher education.

When it was first launched by the UFC in 1992 the scope of the TLTP was limited to 40 or so traditional universities. With the passage of the Higher Education Act (1993) the number of universities in the UK increased from around 40 to over 100. Responsibility for resourcing the newly defined HE sector was now transferred to four regionally based funding councils bearing the following titles:

- Higher Education Funding Council for England (HEFCE)
- Scottish Higher Education Funding Council (SHEFC)
- Higher Education Funding Council for Wales (HEFCW)
- Department of Education Northern Ireland (DENI)

The TLTP is now funded and administered jointly by the four funding councils and embraces all 100 or so higher education institutions including both the 'old' and the 'new' universities.

In phase 1 approximately one-quarter of the projects addressed problems of implementation within single institutions, with staff development of a major component of several of these. Most of the remainder are concerned with courseware development and each involves academics from several institutions. These multi-institution consortia form the backbone of TLTP. The sizes of

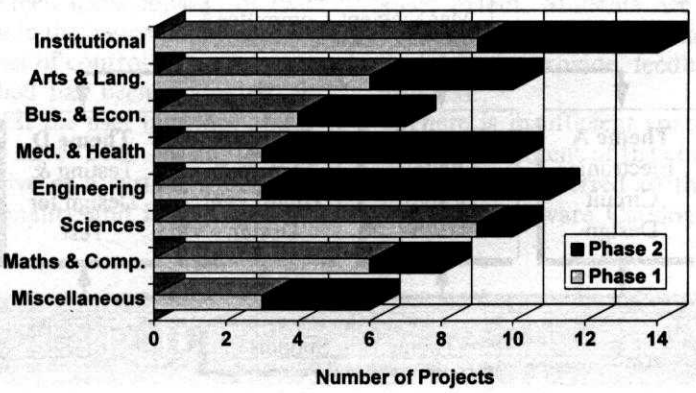

Fig. 1. Distribution of TLTP projects by discipline.

the phase 1 TLTP consortia vary from two to 44 institutional members and first-year grants range in magnitude from £35,000 to £435,000. A similar pattern is evident in the projects that are being funded under phase 2 of TLTP; in this case consortium sizes range from 3 to 52 institutions with first-year grants ranging from £25,000 to £300,000.

The distribution of TLTP projects according to subject area is shown in Fig. 1. Here it can be seen that 11 of the projects directly address engineering disciplines while a further 18 are in the related fields of mathematics, computing, and the sciences. Many of the TLTP projects are using commercially available authoring tools such as Authorware Professional, Toolbook, and Guide for the production of their courseware. Authorware and Toolbox appear to be particularly popular with the science and engineering communities, possibly because they make it relatively easy to incorporate animated graphics into the courseware.

Courseware content initially has to be defined by academics, but thereafter the consortia have adopted a variety of different strategies with regard to implementation. Some consortia are using the services of dedicated Computer-Based Learning Units located within their member institutions whilst others are employing teams of Research Assistants. In one or two cases the task of implementation is being subcontracted to commercial organizations specializing in the production of computer-based training materials.

EDEC—THE ELECTRONIC DESIGN EDUCATION CONSORTIUM

The aim of the EDEC project is to develop computer-based teaching material to support the education of electronic engineers and computer scientists in the design of electronic circuits and systems.

For more than 10 years electronic engineering in the higher education sector has benefited from access to high-quality electronic computer-aided design (ECAD) software provided through a UK-wide scheme called the ECAD Initiative [8]. This had up to around 100 members including universities, research establishments and colleges of further education. A similar European-wide initiative called EUROCHIP was set up in 1989 specifically to promote VLSI design education, and both ECAD and EUROCHIP (recently relaunched as EUROPRACTICE) are now represented in the UK by the Central Laboratory of the Research Councils (CLRC).

Access to ECAD software is essential for a modern electronics education. Electronics design, production, and manufacture relies universally on computer-based processes from the instant of design conception, through the many different implementation styles, to final testing. All students of electronics must gain practical experience of the methods and techniques embodied in these tools by carrying out design exercises similar to those undertaken on a larger scale in industry. However, the software is often extremely complex and the close supervision and support of students using these tools has proved to be very staff-intensive. Computer-assisted learning (CAL) offers the possibility of enhancing the learning environment for students without necessarily increasing the teaching load on staff. For this reason it was decided to investigate the role that CAL might play in the education of electronic engineers.

The EDEC consortium was formed under phase 1 of TLTP to undertake the development of courseware which will enhance the educational value of ECAD tools and help to reduce the amount of staff effort needed to teach electronics design. The members of the consortium are the Universities of Bristol, Essex, Huddersfield, Kent, Manchester and Newcastle, the University of Manchester Institute of Science and Technology (UMIST), Oxford Brookes University and the Institution of Electrical Engineers (IEE). Over 20 academic staff and 16 full-time research assistants are engaged in working on the project, which has a total budget approaching £1 m.

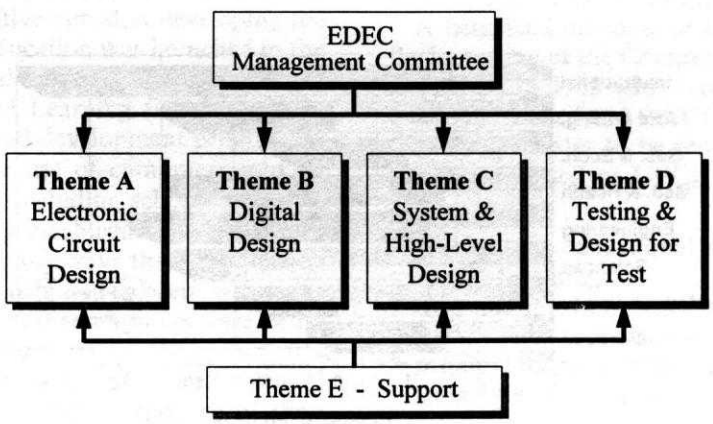

Fig. 2. Structure of EDEC project.

EDEC courseware themes

Development of the EDEC courseware has been subdivided into four major themes. These can be seen in the diagram in Fig. 2 which illustrates the overall structure of the EDEC project. Themes A–D are primarily involved in the courseware production process under the four headings shown in the diagram.

A fifth group, theme E, provides authoring tool support and defines standards that are applied across the whole project. Each theme group is led by a senior member of academic staff from one of the consortium sites. The staff and research assistants associated with each theme meet regularly to agree on courseware content and monitor progress. A management committee comprising representatives from each member institution of the consortium is responsible for steering the project and receives regular reports from the theme group leaders. Over the 3-year duration of the project the aim is to produce a total of approximately 160 hours of courseware.

The EDEC shell

A standard shell [9] has been developed for the EDEC courseware to provide a common framework with a uniform method of navigation and screen layout. By this means it will be possible to ensure that all the courseware produced by the consortium will have the same 'look and feel'. A further feature of the EDEC shell is the flexibility that it gives the end-user (i.e. tutor) to customize the modules to suit his or her particular requirements. This is accomplished by means of a module configuration file which can be easily modified by the tutor to determine the order in which chapters or sections are presented, and even decide on whether certain components should be left out altogether. Additional user-supplied material may also be integrated into the courseware, where necessary, using so-called 'media links'. This material could be a text file or a video clip, for example. The media links file consists of a description of the link, the name of the program used to display the information, the name of the file which the information is in, and a list of pages to which the link is relevant.

The layout of the screen itself consists of two parts: the main area where the course material is to be displayed, and a panel of control buttons and a status message. The shell has been evaluated by groups of students to test the user interface and a number of iterations have been made to the navigation tools to arrive at a system which has all the required functionality and is also easy to use. The format of the EDEC button-bar is shown in Fig. 3.

Authorware Professional has been adopted by the consortium as the standard tool for courseware development, and early versions of the shell were constructed using Authorware. However, problems were experienced with the sluggish response to the Authorware shell to user commands, even on relatively powerful PCs. For this reason the shell has been rewritten in C to produce a Dynamic Link Library (DLL) which can be linked to the courseware modules. Theme C has chosen to use a fourth-generation programming language, Knowledge Pro for Windows (KP-WIN), as its preferred means of implementing courseware. The additional flexibility offered by the use of a programming language has been shown to be necessary if theme C is to achieve the functionality desired from its courseware. However, the theme C material will have the same 'look and feel' as the courseware produced using Authorware, this being achieved by reproducing the EDEC shell in KP-WIN.

Courseware development

It is expected that a major application of the EDEC courseware will be for the use of students who wish to study in their own time and as such it will supplement rather than replace more conventional modes of teaching. As far as possible the material has therefore been designed for use in self-study mode and each module provides self-contained coverage of a particular topic. In choosing the topics to be included in the courseware some thought has been given to areas which can benefit from a computer-based learning approach. A formal procedure has been devised to guide the courseware development process and this involves clearly identifying the learning objectives before working out how they can best be achieved [10]. Interaction is believed to be a key ingredient of successful courseware in that it helps to engage the student's interest and this principle has therefore been embodied in the material produced by the consortium. Extensive use has been made of animation to illustrate dynamic processes and sound and video have also been employed although to a lesser extent. Students are frequently invited to answer questions on the material they have been studying to provide feedback on their rate of progress.

There is insufficient space here to describe the scope and content of the courseware in detail, and the reader is referred to the EDEC entry in the TLTP Courseware Catalogue [11] or the EDEC

Fig. 3. The EDEC button-bar.

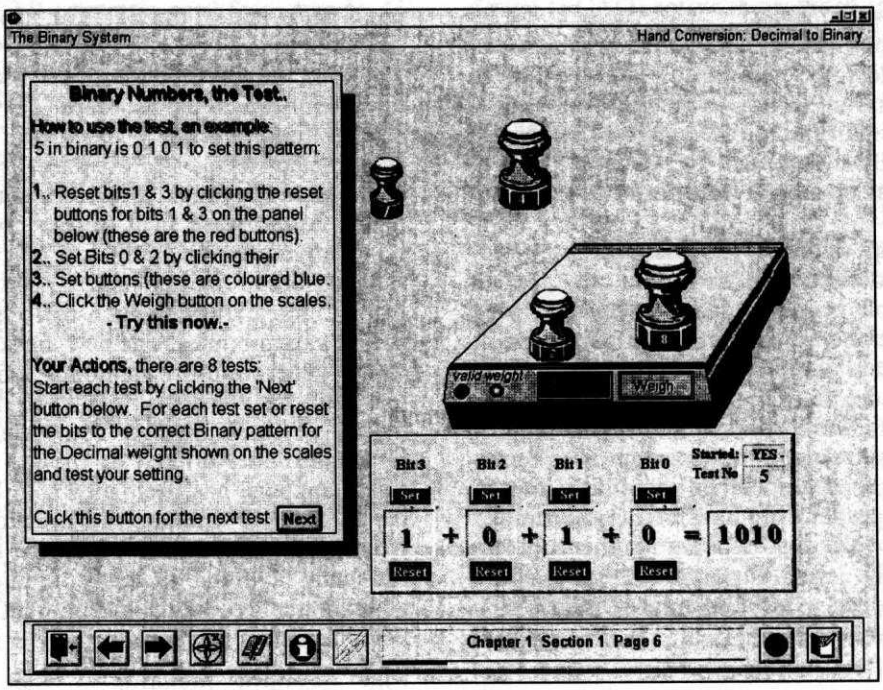

Fig. 4. Screenshot from the digital design module 'number systems'.

World Wide Web pages [12]. To give some idea of the sort of material that the Consortium has produced so far, it is perhaps worth mentioning just a few examples of module content.

In the digital design theme students are introduced to the basic ideas of Boolean logic, number systems, and combinational and sequential logic design through a series of modules that enable them to explore these topics interactively. For example, Fig. 4 shows a screenshot from the number systems module which uses a weighing machine analogy to explain the principles of binary-to-decimal conversion. A number of the modules in the electronic circuits theme make use of a simulated 'electronic breadboard' on which simple circuits can be built and tested. Thus in one example an operational amplifier (op amp) is connected to a variable power supply and a signal generator is used to supply waveforms of varying frequency and amplitude to the input of the device. To introduce an element of realism into the simulation, students find that they must click with the mouse on the on/off switches on the power supply and signal generator in order to switch them on. The op amp's input and output waveforms can be inspected using a simulated oscilloscope which employs animation techniques to create the illusion of a real instrument. This arrangement can be used to illustrate many of the basic properties of op amps, e.g. dependence of closed-loop gain on feedback resistor values, clipping behaviour and so on. Another of the modules from the electronic circuits theme provides students with a design exercise to test their knowledge of instrumentation amplifiers, and a screenshot from this module can be seen in Fig. 5. The exercise is presented in the form of a case study involving the use of strain gauges in a weighbridge which forms part of a system designed to prevent heavy vehicles from using a rickety bold bridge across a river. If the student successfully completes the design, a heavy truck is warned not to try to cross the bridge. On the other hand a bad design leads to the collapse of the bridge and the truck ends up in the river!

Animation is used in a variety of different ways in the digital design theme, e.g. to illustrate the dynamic switching behaviour of logic gates and flip-flops. In other module the differences between analogue and digital control systems are neatly portrayed using animations of the rudder on a ship or the sequence of steps involved in releasing a satellite from the hold of the Space Shuttle. Animation is used extensively in the system and high level design theme as well, in this case to show the data flow and state sequencing associated with graphs representing different architectures.

Consultation has taken place with potential users to determine the content of the courseware that is being developed for each of the four main theme groups. Within the consortium good communication has been maintained through the use of e-mail over the UK's Joint Academic NETwork (JANET). In particular, a series of electronic discussion lists has been set up, one for each theme group, under the NISP Mailbase system [13]. Mailbase has also been exploited as a means of communicating with the potential user community.

Progress reports are presented regularly at meet-

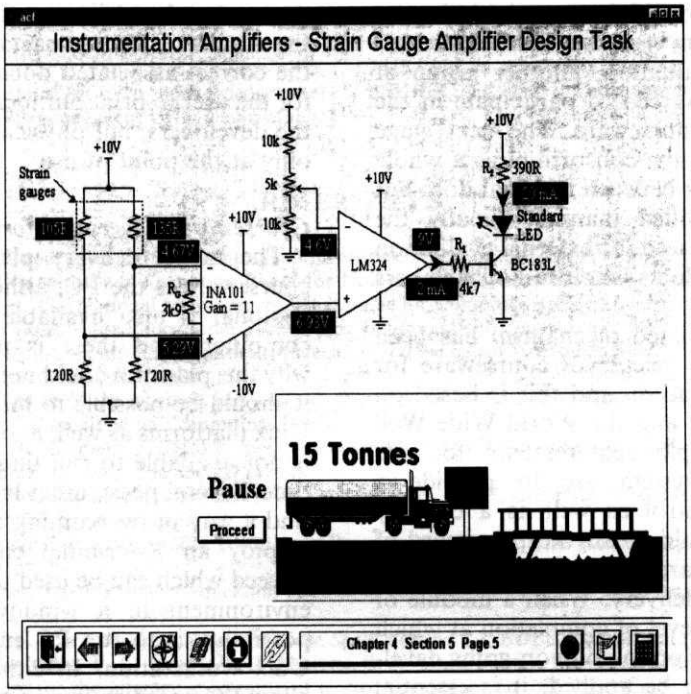

Fig. 5. Screenshot from the electronic circuits module 'instrumentation amplifiers'.

ings of the ECAD Educational User Group (EEUG) which attracts users of electronics CAD tools from nearly 100 higher education institutions in the UK. These CAD users are also the potential users of the EDEC courseware and this forum, therefore, provides an extremely useful source of feedback which can be used to guide the development process. With such a large community of users already using ECAD software, the consortium is in an excellent position to disseminate the courseware it produces and obtain a sound, independent evaluation of the results. The IEE, through its involvement in the consortium, will be able to assist with the evaluation of the courseware and also assess its potential for use in other spheres such as distance learning courses and continuing education.

Courseware evaluation

Evaluation of the EDEC courseware is carried out at several levels in an attempt to ensure that it meets its objectives. The preliminary stages of evaluation are carried out within the consortium although later on the process involves academics and groups of students from other institutions. The procedure is shown diagrammatically in Fig. 6.

A research assistant working on a particular courseware module for one of the themes A–D interacts closely with a 'prime' academic member of staff from the same institution who has agreed to participate in the content definition and development of the module. At regular intervals during the development cycle the module will be passed to another prime academic working in the same general area for evaluation and comment. As the

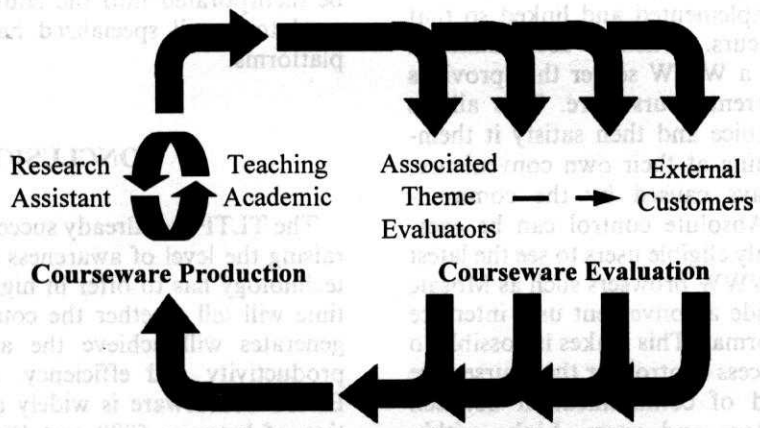

Fig. 6. EDEC courseware evaluation procedure.

content and presentation of the material is further refined, the evaluation process is extended to include the theme evaluation, another group of academics who have agreed to participate in the development of the courseware. The next stage involves evaluation by the consortium as a whole to ensure that overlaps between material does not occur in an uncontrolled manner. Finally the courseware will be released for external evaluation by academics and students who are not members of the consortium.

A centrally co-ordinated mechanism has been devised to control the release of courseware for evaluation and distribution, and this is based on the use of the Internet and the World Wide Web (WWW). The principle requirements for the EDEC distribution system are to provide a means of version control as well as a delivery mechanism which should ideally keep a record of to whom the courseware has been delivered and the date and time of delivery. When a module of courseware reaches a level of completion at which end-user evaluation, as opposed to on-going development comment, can be applied, it is essential that the exact status of production is recorded. Only then can the evaluator's comments be debated, and agreed modifications formally applied; if unrecorded alteration can be made after issue, then formal modification is meaningless in terms of quality control and/or improved capability.

The structure of a module submitted for evaluation, as recorded by the technical management, must be frozen, and all access denied until changes have been formally agreed. At this time a modification record is created, the access restriction is lifted to make the changes, then reimposed at the new level. This record then becomes part of an audit trail, used to monitor the effects of the changes, both to prevent deviation from specification and to assist in deciding the timing and extent of major revisions.

Delivery of courseware via the network can include built-in access control, using various techniques. Both courseware and documentation can be stored in the appropriate formats, created simultaneously and possibly automatically, with changes flagged, implemented and linked so that no discrepancy occurs. When a user makes a request they access a WWW server that provides a catalogue of current courseware. This allows them to make a choice and then satisfy it themselves by downloading at their own convenience, suffering only delays caused by the communications network. Absolute control can be exercised by enabling only eligible users to see the latest authorized issues. WWW browsers such as Mosaic and Netscape provide a convenient user interface using a hyperlink format. This makes it possible to provide not only access control for the courseware but also a method of communication between developers, evaluators and users. Links within announcements can be coupled to authorized material only, delivery made automatically and the details of the transaction recorded. Similarly, the correct associated documentation can be sent for the user to print our locally in the format set by the developers, but physically committed to paper only at the point of use.

Courseware delivery platforms

The target delivery platform for the EDEC courseware is the PC, although Authorware Professional is also available on Apple Macintosh computers and there is no reason in principle why this platform could not be used as well. Ideally it should be possible to mount the courseware on Unix platforms as well, although Authorware itself is not available to run under Unix at the present time. Several possibilities have been investigated to find a way of overcoming this problem. One is to employ an X-terminal emulator such as Vista Exceed which can be used to create a Unix graphic environment in a window on a PC. Another possibility is to run PC emulation software on a Unix workstation. In either case, the aim is to allow PC-based courseware and Unix-based CAD tools to co-exist in a windowing environment on a single screen.

The courseware is being developed on 486DX/50 MHz computers equipped with 8 MB memory, 500 MB hard disk and SVGA colour graphics displays. The default display specification for the courseware is 800 × 600 pixels and 256 colours. This has been found to be the minimum acceptable resolution if multiple windows are to be displayed on the screen simultaneously. Delivery platforms must be capable of running Windows and the minimum specification is a 486 processor with 8 MB memory and SVGA graphics. Distribution of the courseware will initially be achieved electronically using the network as already described in the previous section. The possibility of distribution on CD-ROM is currently being investigated, in which case access to a CD-ROM drive will also be necessary. The Soundblaster audio card has been optionally specified as a standard in cases where a sound capability can be utilized. Video clips conforming to the Windows AV1 standard may also be incorporated into the courseware without the need to install specialized hardware on delivery platforms.

CONCLUSIONS

The TLTP has already succeeded in significantly raising the level of awareness of what multimedia technology has to offer in higher education. Only time will tell whether the courseware that TLTP generates will achieve the anticipated gains in productivity and efficiency. Assuming that the EDEC courseware is widely adopted, the education of between 5000 and 10,000 students in the UK should be considerably enhanced while major

savings in staff time could be achieved in core teaching areas in first and second year courses.

Acknowledgements—The authors wish to acknowledge the contributions of all of their colleagues in the EDEC consortium whose names are too numerous to list here. The Teaching and Learning Technology Programme is jointly funded by the four UK higher education funding bodies, HEFCE, HEFCW, SHEFC and DENI, whose support is gratefully acknowledged.

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