

Computer-Aided Learning in Artificial Neural Networks

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Abstract—This paper describes the development and evaluation of a computer-aided learning (CAL) package for a graduate course in artificial neural networks (ANNs). The package has been evaluated over a period of two academic years, both as an educational supplement to a conventional lecture course and as a completely self-sufficient, remotely taught course. The course is accessed via the World Wide Web (WWW). The course features Java applets for animation/demonstration purposes, employing the MATLAB computational engine for interactive examples and assignments. In an effort to provide a classroom-like environment, an interactive discussion forum is provided, along with weekly lecture summaries from the conventional lecture course. Automatically marked question pools are available for self-assessment.

Index Terms—Artificial neural networks (ANNs), computer-aided learning (CAL), MATLAB, online learning, World Wide Web (WWW).

I. INTRODUCTION

IN THE CURRENT era of computer literacy and proliferation of personal computers (PCs), there exists considerable scope for the exploitation of computing resources for educational purposes. Indeed, the Institute of Electrical and Electronics Engineers (IEEE), Piscataway, NJ, has recently endorsed the potential of World Wide Web (WWW)-based learning materials [1]. However, many other educational media also exist, and it is the judicious choice of appropriate computer-based materials that truly exploits this technology to its best advantage. Engineering disciplines, whose theory, by nature, can be computationally intensive and whose understanding can be enhanced through graphical analysis, stand to benefit considerably from such technology. In addition, there is also a need to provide an implementation that maximizes the potential use of this medium and not simply resort to nothing more than an electronic textbook. This provision is important if a cost-effective and invigorating environment [2], [3] is to be developed.

Some consideration must also be given to the suitability of computer-based educational material as either support material or a purely stand-alone package. For example, graduate students in the School of Electronic Engineering in Dublin City University (DCU), Dublin, Ireland, prefer to attend lectures, although the complete course is available online. However, this is a result, in part at least, of the more traditional educational environments to which these students have been exposed over a number

of years, reflecting the low proliferation of more diverse educational techniques that have recently become available [4]. Nevertheless, these students still make use of aspects of the CAL package that are not so easily captured in the traditional setting, for example, the use of multiple choice questions (MCQs), which are instantly marked online.

Perhaps the most significant step in the application of technology in education comes from the marriage of computing and communications, which offers both extensive access and a powerful educational environment on the same platform [5]. This combination is the focus of the educational module described in this paper. The subject area that the module addresses is artificial neural networks (ANNs), which require considerable computation in their evaluation and use, making them an ideal candidate for a CAL package.

The educational module described in this paper lies within the “Master of Engineering in Electronic Systems” (M.Eng.) program at DCU. This is essentially a one-year taught Master degree program in which students choose eight taught modules and complete a four-month project. In conjunction with this program, there is an additional possibility of remote access for part-time students, who are generally in full-time engineering employment. This remote-access program offers the program modules via the Internet and is termed “Remote Access for Continuing engineering Education” (RACeE) [6]. To the best of the authors’ knowledge, it is the only available interactive, remotely taught online course on ANNs, although there are a significant amount of available online notes, tools, and algorithms for ANNs [7]. Related works, however, include documented traditionally taught ANN courses [8], [9]; remotely taught ANN courses [10], [11]; and non-ANN (but engineering-related) courses delivered online [12], [13].

The remainder of the paper is organized as follows. Section II addresses the motivations and approaches available in CAL, while Sections III and IV outline the details of the ANN course and the facilities available in the CAL-based course, respectively. The remaining sections address course evaluation and course maintenance issues. Broad conclusions based on the authors’ experiences are provided in Section VI.

II. MOTIVATION FOR CAL

In this section, the advantages of an Internet-based CAL environment will be outlined, while observing the benefits of more traditional educational modes that may be difficult to re-create. In addition to its obvious use in a distance-learning scenario, CAL can also be used to enrich the classroom experience through the use of a data projector. However, in remote-access mode, many of the unique advantages of CAL

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are realized. Nevertheless, some care needs to be given to the aspects of the classroom that have led to its success as the most prolific learning environment. There are five principal issues involved here.

- 1) *Pacing of learning material*: Material is presented in bite-sized chunks in a logical sequence, with an even pace appropriate to the course duration.
- 2) *Gestures and movements*: These add to the learning experience and give it a “live show” feel [14].
- 3) *Interpersonal skills*: The interpersonal skills of the lecturer enrich the learning experience, and the interaction between classmates can be very beneficial [15].
- 4) *The competitive environment*: The classroom environment can be beneficial in motivating students to learn course material. However, such competition can also be destructive, with the possibility of unfavorable outcomes, such as anxiety, low esteem, and poor relations between students.
- 5) *Supplementary material*: Course material is focused on requirements for the given module. Students are referred to supplementary material only as required [16].

There are several main benefits of CAL as it relates to the distance-learning environment.

- Self-paced learning is available, which is suitable for all abilities [17].
- Graphics, animation, and simulations are easily incorporated.
- Using hypertext, there can be many ways to access the same piece of information [18], with the caveat that some parts may never be accessed, and students may be left unsure as to whether they have covered all the necessary material [19].
- CAL is an ideal medium through which continuing professional development (CPD) may be accomplished, since the clientele is normally composed of mature learners with significant time restrictions [11].
- Computer-based testing can easily be integrated with a CAL package [20], giving students instant feedback, which can be either directed or undirected [21].
- On a more subtle level, CAL offers relative freedom from discrimination because of physical characteristics (or racial/cultural factors) which may arise in the traditional classroom [22]. (It also provides a solution for those with physical disabilities for whom attending and navigating a university campus might prove too difficult.)

As a facilitating platform for CAL, the Internet has received considerable attention over the last decade. With the first Web browser introduced in 1993, an estimated 20 million Web sites established by the year 2000, and current connectivity of PCs increased by 45 million in the first quarter of 1998, it is clear that the Internet is a great resource for CAL-based courses [23]. There are several important beneficial characteristics that relate to the use of an Internet-based CAL platform.

- Accessibility is unsurpassed.
- A diverse variety of media is supported.
- Java allows for the development of interactive examples.

- Communication between users and lecturers is facilitated via e-mail and other conferencing tools, such as mailing lists and message boards.
- Course material is stored as a single copy that is easy to update.
- A wealth of related information is accessible via hyperlinks, but this availability has its own dangers, e.g., information overload.

III. THE ANNS COURSE

The ANNs course, like the other modules in the M.Eng. degree program, is a 36-h lecture course with three additional assignments, each requiring approximately 8 h of work. Course lectures are scheduled for 12 weeks (consisting of a 3-h lecture block per week), followed by a study week and a week of exams. Assignments count as 25% of the overall course mark. The course outline consists of the following.

- Introduction to ANNs.
- Simple neural networks.
- Multilayer perceptron networks.
- Radial basis function networks.
- Dynamic neural networks.
- Self-organizing feature maps.
- Hopfield networks.
- Data preprocessing.
- Application of ANNs.

Further information on the course content can be found at [25]. Those wishing to learn more about ANNs in a more conventional setting are directed to [24].

Placed against the merits and demerits of Internet-based CAL, as documented in Sections I and II, this course provides an ideal test bed for the evaluation of such an environment for several reasons.

- The course forms a part of computer science and is very computationally intensive.
- Considerable use can be made of graphics, diagrams, etc., in the visualization and analysis of ANN topology, parameters, and variables.
- The course is set at the graduate level, and students are generally experienced and mature learners, capable of pacing themselves.
- The course has a CPD function as part of the RACeE program offered by the School of Electronic Engineering at DCU.
- A lecture-based course already exists upon which the CAL-based course can be built.

IV. CAL PACKAGE IMPLEMENTATION

The main decision when embarking on the development of a CAL package is whether to adopt a commercial courseware development package or go for a custom design [26], [27]. Two commercial packages were evaluated—WebCT [28] and Top-class [29].

Both packages provide a number of tools that aid the lecturer in presenting and maintaining their course. The packages allow

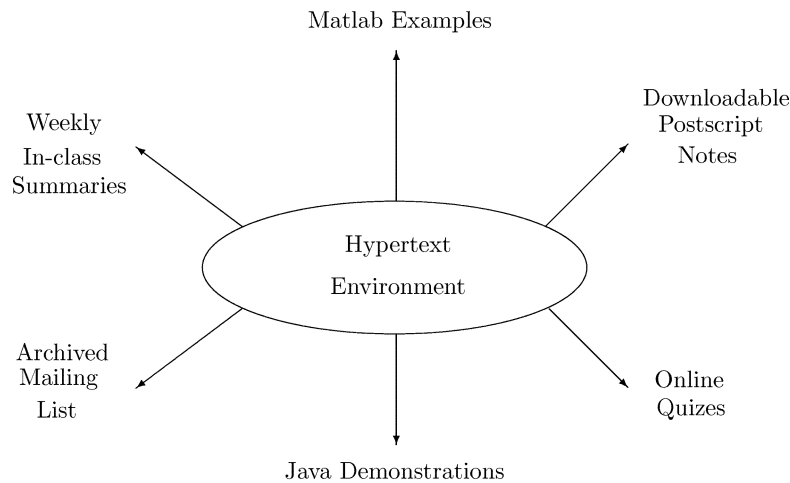


Fig. 1. Proposed course structure.

for the inclusion of online quizzes and tutorials, conferencing and e-mail, and features such as calendars, learning goals, and page annotations. Each student has his/her own home page with a unique log-in ID, allowing the package to recall individual settings for each user. For instance, upon log-in, the option is given of returning to the last page covered in the previous session. Using the unique log-in IDs, the package keeps track of each student's progress through the course material. Management of grades and other student details are also covered. More information on these and other course development packages are provided in [30] and [31].

The main difficulty with both packages, however, is the pricing structure. Course development is free, but costs are incurred on a "per use" basis, related to the number of students taking the course. This unknown cost, and its associated administration, coupled with the availability of in-house expertise, led to the choice of a custom design.

Another decision entailed the choice of mechanism with which to implement interactive examples. This dilemma was well documented previously [32], with mixed conclusions. Although most engineers are familiar with the MATLAB environment [33], Java offers interactivity with the Internet environment, even if it lacks some of the technical computing features. However, both tools have many similarities: both are relatively slow (both MATLAB macro and Java byte code are interpreted) but reduce server load (by running locally on the client machine), provided that the MATLAB code is downloaded and not run directly from the server. One important distinction, however, is the considerable programming time required with Java as compared with MATLAB, which has high-level functionality for graphics, mathematical functions, and a dedicated neural network toolbox [34]. A further option (VCLab) [35] allows MATLAB to run directly as a "subprocess" via HTML; however, the trials made by these authors resulted in relatively slow update times, particularly during scrolling of Web pages containing three-dimensional (3-D) images from MATLAB. Current versions of the software may offer an improvement.

The authors decided to abandon VCLab and to utilize both Java and MATLAB for animation/interaction. In total, four Java applets were written, which provide a conceptual introduction to difficult sections. In contrast, the downloadable MATLAB functions re-create the examples documented in the notes and provide the option of experimenting with the function parameters and variables.

One of the chief difficulties in developing an Internet-based, mathematical/engineering package is the difficulty with which mathematical symbols are incorporated into HTML. Currently, these are included as images, which push up the memory requirement significantly and fail to allow the characters (which are stored as bit maps) to be automatically scaled to suit the document font size. One eagerly awaits the acceptance of the HTML 4.0 standard by the popular browser developers, which provides for mathematical markup via MathML [36].

Inevitably, authoring environments for HTML, including mathematical notation, will improve. An interim possibility for mathematical symbols is HotEqn [31], which is a Java applet that allows the inclusion of mathematical equations and symbols within an HTML document. The software makes use of the LaTeX [37] notation to code its examples. Even though HotEqn does not use images, it has to interpret the LaTeX code within the HTML document and then download the relevant fonts. This requirement places an extra load on the Web server since it has to first deliver the document that was requested and, having done that, deliver the fonts requested by HotEqn. For this reason, HotEqn was not used in place of the standard image files.

Specific features of the CAL environment will now be outlined, with an overview of the course mechanisms provided in Fig. 1.

A. Password Protection

Since both M.Eng. and RACeE degree programs are fee paying, and to avoid server overloading, access to the CAL environment is restricted through password protection. This

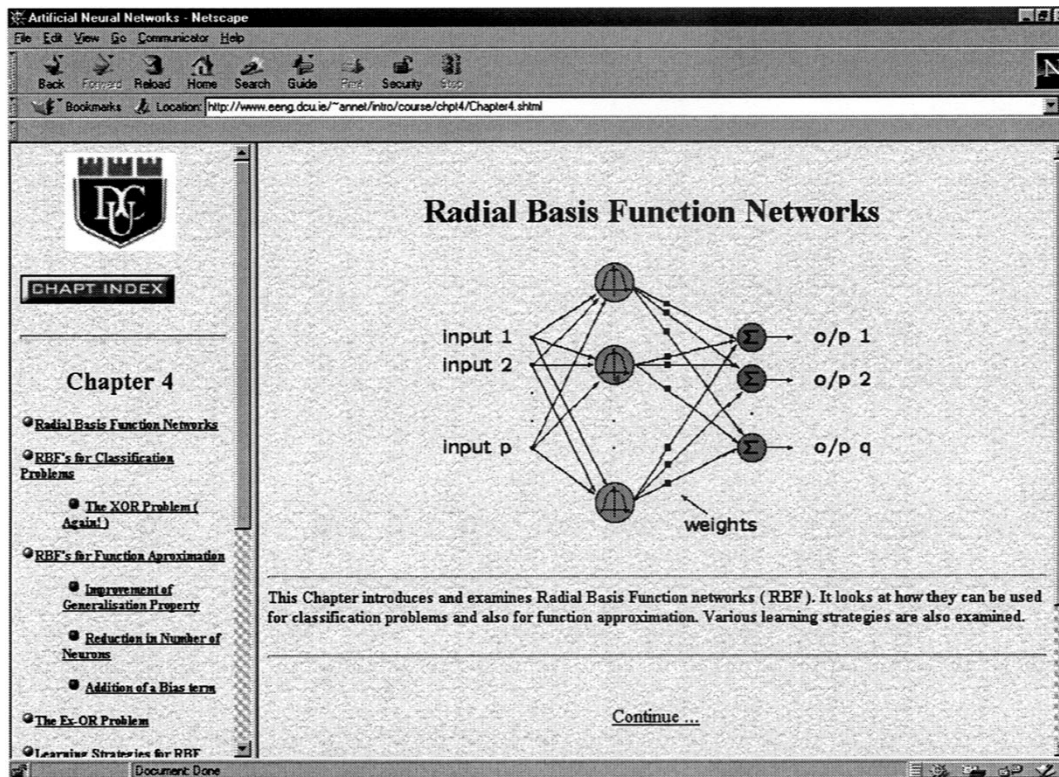


Fig. 2. Example of navigation through course.

protection is simply performed using the file/directory protection system in the Apache Web server software.

B. Navigation Through Course

Navigation through the course is accomplished by the following.

- 1) The nominal sequential layout of the course, using the back/forward buttons on each page.
- 2) Hyperlinks, which direct the user to
 - a) previous areas of the notes for revision purposes;
 - b) more detailed explanations for various items;
 - c) other websites directly related to the item under study. For example, there are links from the section on Kohonen self-organizing feature maps (SOFM) to Teuvo Kohonen's Web site at Tampere University, Finland [38], which contains diverse examples of the use of SOFMs.
- 3) A hyperlinked contents frame, which is always visible at the left-hand side of the browser window.

As an example, Fig. 2 shows the contents menu and local hyperlinks. In addition to browsing through the HTML notes, users also have the option of downloading a set of postscript notes. Although these do not have the same versatility, they may be useful for a first pass, particularly for students who have very slow Internet connections or who find the connection usage cost prohibitive.

In addition to linking to other Web sites, elements of this course are utilized in other courses, including a graduate course on ANNs in the US.

C. Java Applets

The Java applets, where available, are located at the start of each chapter and are intended to provide a conceptual introduction to such sections. They are not intended to require specialist knowledge; rather, a "see by doing" feel is intended. Java applets are included for the sections:

- multilayer perceptrons;
- radial basis function networks;
- Hopfield networks;
- self-organizing feature maps (SOFMs).

Where possible, the applets treat a well-known example type. Fig. 3 shows the Java applet for the Hopfield section of the course, corresponding to an image restoration/recognition problem.

D. Course Assignments

Three course assignments are required.

- 1) *Multilayer perceptrons*: The student is required to solve the EX-OR problem using two- and three-layer networks. The assignment includes topology determination and examination of the I/O surface implemented by the network.
- 2) *Radial basis function networks*: The student is required to synthesize a chaotic dynamic function (the Henon map) and perform single and multistep predictions of the system output. Topology determination and examination of the I/O surface are also required in this assignment.
- 3) *SOFM*: In this assignment, students are given a template program that maps two-dimensional (2-D) data using a 2-D network lattice. The requirement is to solve the 2-D

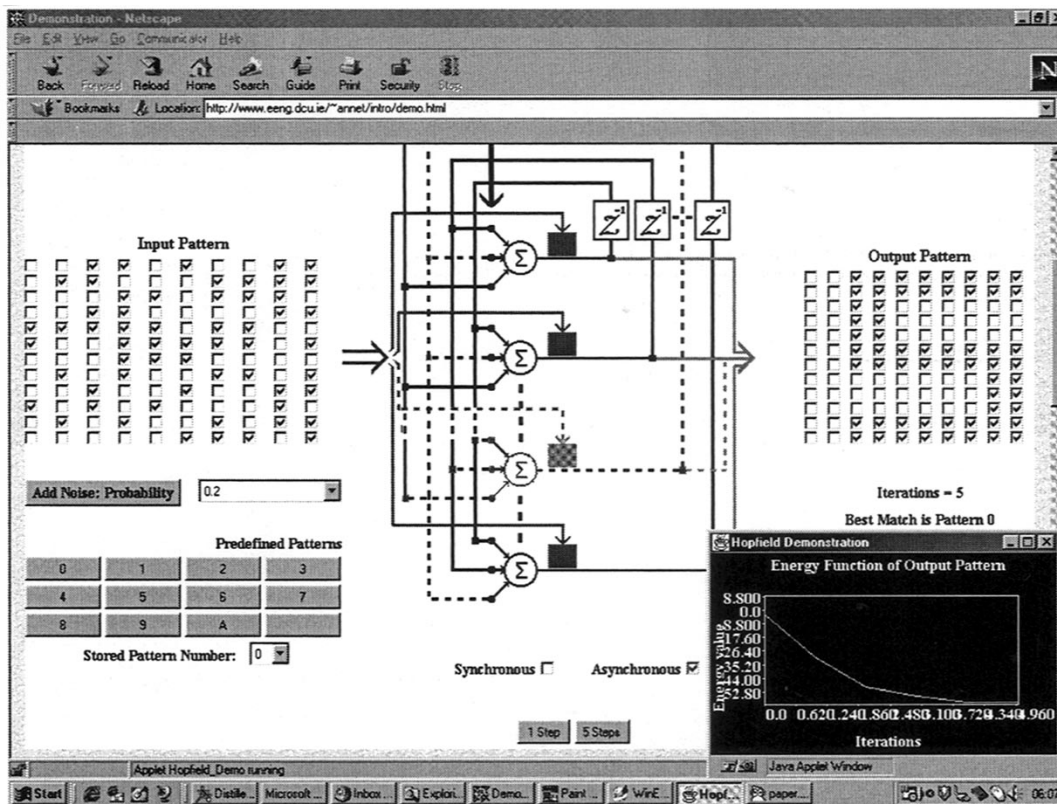


Fig. 3. Java applet for Hopfield section of course.

vector quantization problem using a one-dimensional (1-D) network topology.

Assignments are programmed in MATLAB macro. Remote students are required to obtain a copy of the student edition of MATLAB. Reports are submitted electronically, usually as attachments in either Microsoft Word or LaTeX (postscript) form.

E. MCQs

MCQs are available at the end of each chapter. A set of ten questions is presented to the student from a pool of 30 or more. Questions are drawn from the pool at random, allowing the student to effectively retake the section test a number of times. Submitted tests are marked immediately by the server and the results returned to the student via the browser. If desired, students can use the “back” button on the browser to retake exactly the same test and check that their revision has been successful. The results of the tests are not used in any way to grade the students, but the test statistics are available to the course leader for review.

F. Course Examination

With remote access under the RACeE Program, two different study modes are available. The first mode treats the course as part of the M.Eng. degree program, where students take the examination and build up credits toward their degree. In the second mode, students have access to full course materials and may submit assignments, but there are no examination requirements. The second mode is usually more suitable in the case of CPD. Currently, the course examination is only available at DCU, and

remote students attend at the same time as full-time students. This procedure reflects the difficulty of synchronizing examinations at different locations. The examination is written, 3 h in duration, with no requirement for computer simulation. Other options for the examination, which would allow it to be more geographically diverse, are currently being examined, but such an extension, by necessity, incurs a significant administrative penalty.

G. Course Bulletin Board

Upon enrollment, each student subscribes to an electronic mailing list, which is archived on the Web server. Thus, every message submitted to the list is sent to each course participant and is permanently available for review on the archive. This function serves three purposes.

- 1) The archive serves as a bulletin board for course announcements.
- 2) E-mail inquiries are handled through the mailing list, allowing each student (and the course leader) to benefit from all the interactions, both questions and answers.
- 3) In order to help external students with pacing, weekly summaries that document the salient points covered in the lectures are posted.

An example of the archive is provided in Fig. 4.

H. Statistics Generation

Course usage and MCQ statistics are automatically logged and are available for review by the course leader. A program



Fig. 4. Sample bulletin board dialog.

has been developed (using Pearl) to present this information in tabular form. Course usage statistics (for each access incidence) provide the following information:

- user name;
- the page that is accessed;
- date and time;
- remote host address;
- browser type.

This information can be compiled to give “per page” statistics, if required. Similar information is available from the MCQs (for each submission) as

- user name;
- time and date;
- answers given;
- grade received.

These statistics, along with course review forms, form the basis of year-to-year course revisions.

V. COURSE EVALUATION

A student evaluation of the course is performed using a semistructured questionnaire. Each course evaluation form contains ten MCQs and four free-format questions. The MCQs

are graded 1 → 5, with 5 indicating full agreement. A sample size of 11 + 12 was available over two years of the program, with a mixture of remote-access-only students and those who used it as supplementary material. Table I shows the MCQ responses, indicating that, in general, students find the experience a very positive one, with particular emphasis on the presentation quality, course navigation, MATLAB examples, and downloadable notes.

Although not widely completed by the students, those that completed the free format questions tended to use them to back up the feelings expressed in the MCQs. The main recommendation was the inclusion of more real-world applications and implementations of ANNs.

An attempt was made to utilize the capability of the package to record statistics on page and quiz usage. However, because of relatively small sample sizes, correlations of MCQ results with final examination marks are rather unreliable. However, a correlation coefficient of 0.32 was obtained between final mark and MCQ usage and a slightly larger figure obtained when the average MCQ mark was weighted by the MCQ usage score. Most significant, however, was the consistently good results obtained from users of the MCQs, relative to nonusers.

In general, the authors were very encouraged with the overall student reaction to the course, both in terms of the formal evaluation and informal comments from students over the duration of the course. It was particularly noteworthy that students who took the course exclusively through remote access scored highly (the top achiever of the 1997–1998 course was a remote-access student), with the course receiving considerable usage from students using it as supplemental material. However, superior marks could easily accrue from the fact that remote-access students are better motivated. In many cases, more supplemental usage (in terms of page hits) per student was recorded than was usage on a purely remote basis.

VI. CONCLUSION

The development of this stand-alone WWW-based course has presented an interesting challenge and involved a considerable number of decisions in the layout, content, and choice of on-line facilities offered. This section will attempt to identify the problematic areas, offer some insight, and, hopefully, some useful advice, based on our experiences.

Over the two years that the course has run, many useful spin-offs from the course have been identified (e.g., the introduction of engineering students pursuing final-year projects or research theses in the neural network area to related course material, especially at times when the lecture course is not running). The CPD benefits have been documented previously. Also of major benefit is the geographical flexibility of the course, allowing access worldwide, within the reaches of the Internet. In areas where Internet access is a problem, or transmission speeds are prohibitively low, the course is easily accommodated on a CD-ROM. In this case, the server is only required for online MCQs and the bulletin board.

A considerable amount of time has been expended in the development of this course. Starting from the basic lecture course, the online course took approximately 2.5 man-years to develop,

TABLE I
RESPONSES TO MCQs

Course aspect	Year 1 (11)	Year 2 (12)
Presentation quality	4.27	4.18
Ease of access to course	4.45	3.9
Ease of navigation through course	4.36	4.27
Usefulness of MATLAB examples	4.09	4.18
Usefulness of Java examples	1.82	3.36
Usefulness of mailing list	3.60	3.00
Usefulness of downloadable postscript notes	4.30	4.54
Usefulness of additional links	3.80	3.80
Usefulness of weekly summaries	4.00	3.80
Usefulness of on-line quizzes	3.45	3.36

with many short cuts taken in the recommended full development process for CAL courses. Fortunately, there has been minimal overhead in terms of annual maintenance, the basic requirements being to archive annual statistics files, reset the bulletin board, provide new user names/passwords, and update the available past examination papers, in addition to any required modification to the basic course material. In order to achieve the maximum benefit from course development time, efforts should focus on those course aspects that give (or are likely to give) maximum usage and benefit. The authors now attempt to document findings in this regard.

One great disappointment was the poor utilization of the Java examples. These were intended to provide a user-friendly, interactive introduction to course sections. However, many students skipped these altogether and did not even try them. On the other hand, students made considerable use of the MATLAB examples. This preference is significant, considering that most MATLAB examples were generated to produce the (lecture-based) course examples with minimal overhead required to add some comments and provide the download mechanism. In contrast, the Java examples were provided specially for the online course and took approximately 0.5 man-years to produce. This fact may add further spice to the MATLAB-versus-Java debate [32]. Other very profitable additions were the bulletin board, which is vital for remote-access students, and the MCQs, which, although time-consuming to produce, seemed to be worth the effort.

The generation of statistics is relatively straightforward to implement via Pearl CGI scripts embedded using server-side includes (SSI). While the usefulness of these numbers is still unclear, they do provide a clear indication of course usage, and the availability of the MCQ usage history is particularly beneficial in getting an indication of general student ability with reference to the course standard. There also seems to be evidence that supports the idea that students who perform well in the MCQs, even after repeated trials, perform better in the final examination.

Final comments relate to the development environment. The choice of development environment is not trivial. The environ-

ment provides the structure that may inhibit or facilitate the development of an effective course. Although initially attractive, the prospect of using a commercial development environment was relinquished, mainly for reasons of flexibility, both in structure and administratively. The pricing structure of these packages is on a per-use basis, which implies an ongoing cost for the lifetime of the course. This structure is burdensome, administratively, and the idea of an unknown implicit future cost is neither attractive nor convenient for any budgeting system. There is also the possible difficulty of software upgrades being incompatible with different course versions. The authors feel comfortable with the choice of a custom design.

Independent of the development environment, it is inevitable that WWW-based CAL packages will rely on HTML for text and hypertext. The authors look forward to the day when MathML will be supported by the popular Web browsers, which will ease course development and maintenance considerably. Finally, the authors would encourage readers to view the package at <http://www.eeng.may.ie/~annet>. User names and passwords for access to the complete course can be supplied to appropriate persons upon request.

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