Pergamon

Comput. & Graphics, Vol. 18, No. 3, pp. 269–275, 1994
Copyright © 1994 Elsevier Science Ltd
Printed in Great Britain
0097-8493/94 $6.00 + .00

0097-8493(94)E0007-K

Computer Graphics in Education

THE DESIGN AND DEVELOPMENT OF DISTANCE LEARNING MATERIALS FOR GRAPHICS AND VISUALISATION

C. C. LILLEY and F. LIN
Computer Graphics Unit, Manchester Computing Centre, University of Manchester, Manchester M13 3PL, UK and Department of Computer Science, University of Manchester, Oxford Road, Manchester M13 9PL UK

W. T. HEWITT
Computer Graphics Unit, Manchester Computing Centre, University of Manchester, Manchester M13 3PL, UK

and

T. L. J. HOWARD
Department of Computer Science, University of Manchester, Oxford Road, Manchester M13 9PL UK

Abstract—Effective means of student learning and course delivery are discussed in the context of a set of distance learning training materials that are being developed for the UK higher education community. Design decisions are explored and the format of the materials explained. A distinction is drawn between the needs of computer scientists and of other students for core graphics training and the relationship between graphics and visualisation training examined.

1. INTRODUCTION

The authors are producing a modular set of training materials on the use of computer graphics and scientific visualisation for the UK higher education community. Part of a nationally funded Information Technology Training Initiative, the project is jointly hosted by the Department of Computer Science, University of Manchester, and the Computer Graphics Unit, Manchester Computing Centre.

To avoid confusion, in the present paper the term *students* will be used to refer to those who are taught—be they Ph.D. students, research assistants, or staff—and the term *presenters* will refer to those who deliver the material.

2. SCOPE

We envisage 10 modules in the series:

- Standards for Computer Graphics
- Colour in Computer Graphics
- Visualisation 1: Graphical Communication
- Visualisation 2: Graphical Exploration
- Geometry for Computer Graphics
- Lighting and Shading
- Curves and Surfaces
- Non Uniform Rational B Splines (NURBS)
- PHIGS Programming
- PHIGS PLUS Programming

3. AUDIENCE

The materials are intended to be delivered to an audience of postgraduate or postdoctoral scientists, engineers, or medics who have little or no prior training in computer graphics. These people are interested in the topic as a tool to accomplish useful work to further their research, rather than as an end in itself. This is an important distinction that will be returned to later; it means however, that much existing computer graphics teaching material is not optimal for this audience.

Computer Graphics and Scientific Visualisation are not widely taught at an undergraduate level. In a postgraduate setting, commercial courses are too expensive to be justified and departments often do not have the resources to put on courses themselves; thus these subjects may be picked up in an ad hoc manner. As a consequence, the powerful tools of computer graphics and scientific visualisation may be inefficiently applied or underutilised; expensive hardware may not produce the productivity gains that were envisaged when the purchase was originally justified. What is needed is a source of readily available and affordable learning materials that can fill this training gap.

4. DELIVERY

There are various methods by which teaching on these topics could be delivered. Major considerations influencing our choice were a desire for wide dissemination and a useful life exceeding the fixed 3-year term of the project. Thus, methods such as putting on a series of lectures and live cable broadcast were not considered. An additional reason not to select the second option, which has been popular in some countries, is the lack of a pervasive academic satellite and cable TV infrastructure in the UK. We were also anxious that students had some means of feedback to presenters, and were able to use interactive, 3D graphical programs. This tended to rule out other methods:

- a series of videotaped lectures
- PC based CAL programs.

At the time the decision was made, the majority of CAL software was PC based and was weak in the area of integrating computer graphics. PCs did not then have 24-bit colour screens or enough processing speed to maintain an interactive response when manipulating 3D models.

An ideal situation would be for presenters at each site to have the time and resources to research, design, and write their own courses. This approach, while providing courses tailored to each group, would involve considerable duplication of effort. Further, departmental staff who end up supporting computer graphics are generally not doing this as a full-time job; they have an interest in, but not necessarily an expert knowledge of, the subject. Such staff often have an unofficial role as graphics gurus, but are unable to spare the time to research, design, and prepare training courses. Academic staff concentrate training efforts on the main areas of expertise and research in the department, and rightly so.

What seems to be needed is a set of off-the-peg, ready written teaching materials that can be acquired by presenters and either used as is or customised to suit local interests. This, it is hoped, will result in a considerable saving of effort for presenters, such that putting on badly needed local courses becomes feasible. The fan-out from authors to presenters to students ensures wide dissemination. Providing a complete teaching pack allows the courses to be delivered year after year without recurrent costs. In addition to eliminating travel costs, local courses allow students to use the same graphical workstations during teaching that they will use in practice; it also allows interactive demonstration software to be used.

5. MATERIALS

We seek to provide complete sets of ready-written materials suitable for running a course, which can be readily extended to refer to local facilities or interests. The particular needs of the students and presenters have had a major effect on the type of materials it was thought useful to provide.

It is the authors' belief that students learn best what they perceive an immediate need to know. In the courses, care has been taken to explain why particular topics are being studied, to show a practical benefit as soon as possible, and to refer back to more difficult concepts later in a module to show that the effort was worthwhile.

The composition of each module varies according to need, but typically includes:

- Illustrated student notes;
- A variety of visual aids and supporting material;
- A workbook of exercises;
- Demonstration software; and
- A resource list.

The design decisions behind these components will now be explained.

5.1. *Notes*

It is a common finding that a new subject is clearly understood at the time it is presented; several weeks later, when the time comes to use it, the hastily scribbled notes and photocopied bulleted points that frequently pass for handouts are less than illuminating. We aim to produce a comprehensive and attractively illustrated set of student notes that can be used as an initial source of reference after the course is over, reducing the need for textbooks whose topic is not the students' area of research and whose purchase can thus be scarcely justified.

A single, bound set of notes is provided with each module. These notes may be freely copied in the department, or alternatively additional bound copies may be ordered at cost.

5.2. *Visual aids*

Audio-visual facilities available for departmental training are varied, although it is the authors' experience that an overhead projector (OHP) is frequently available. Slide projectors and video equipment can generally be found somewhere in the department; multimedia laboratories, although on the increase, are presently scarce resources. Accordingly, the main visual aids are overhead transparencies that can be used in a small seminar or medium lecture theatre setting. To support the presenter, small cue cards are provided, containing important points about each slide, together with a miniature version of it (for identification) and space for personalised notes.

If a department is interested in teaching computer graphics, it is reasonable to assume that some sort of graphics workstations are available, although these may not be linked to a video projection system and there may not be very many of them. Demonstration programs are provided that can be run in a small seminar setting, or during a lecture if video projection facilities are available.

Figure 1 shows an example of such a demonstration program, designed to show mixing and matching of colours using a variety of colour models. As this may well be impossible, we have striven to make the same points on the OHP transparencies, often using still frames transferred from the demonstration. This, we hope, gives the maximum flexibility. The demonstrations can also be run after the lecture, either in a group laboratory-type setting if there are enough workstations, or on an individual, ad hoc basis by the students.

5.3. *Hands on*

What is heard is forgotten; what is done is lost. A close interleaving of teaching and practical experience, coupled with the opportunity for frequent review provided by comprehensive notes, would seem to offer the best hope of maximising retention.

Many modules include sample code that may be examined, modified, experimented with and incor-

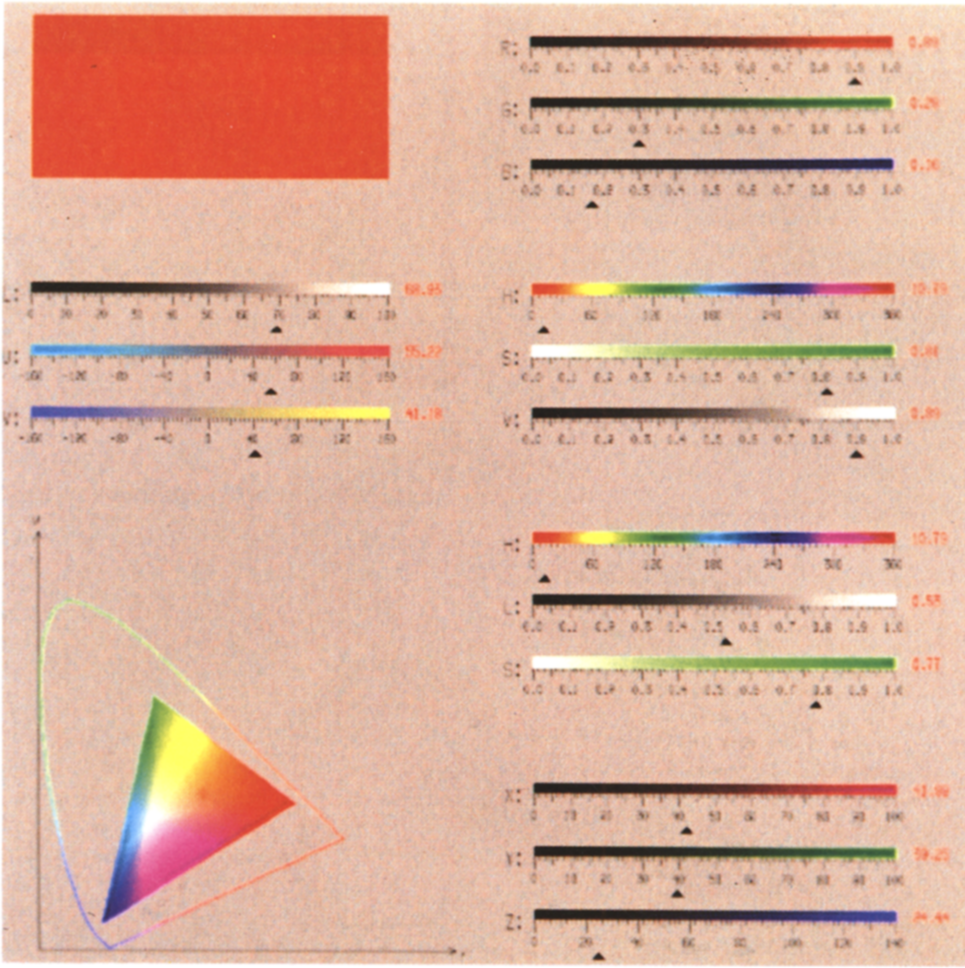

Fig. 1. One of the demonstration programs developed for the Colour module.

porated into other programs as building blocks. For more advanced students, the source of the demonstration programs may also prove instructive.

In some cases there are workbooks with questions to answer, things to find out, short utility codes to write or longer, project-style challenges. Some demonstration programs are intended to be suitable for interactive exploration of a particular concept, a graphical "what if." Figure 2 shows such a program, designed to give direct experience of geometric transformations by interactively altering the transformation matrices. The most satisfying practical work is of course devised by individual students, as the application of new knowledge provides opportunities to advance their work.

Of the 10 modules in the course, 2 differ from the others in that there are no lecture materials; they use self-paced learning. While the other modules address particular topics such as colour, or curves and surfaces, these two deal with programming graphics using the PHIGS and PHIGS PLUS international standards.

Although they are backed up by the material in the other modules, the intensely practical nature of graphics programming can only be taught, we feel, by doing it. Divided into a number of topics, the pair of modules give a planned progression from simple wireframe graphics to interactive, lit, and shaded models. At each stage, the student produces something; there is an end result, however modest, and thus a sense of achievement. Theory is kept tightly coupled to its practical application and the advantages that accrue from knowing a particular topic are immediately presented. In this way, interest and motivation are, we hope, maintained. This visual feedback is a particular strength of teaching graphics as opposed to other types of programming.

For each topic there is a workbook that is worked through sequentially. This gives a sense of progress. Some parts of a workbook are designed to be used online, using demonstration software or creating programs. Often the latter will be extensions or corrections of supplied code examples, so that a visual result is rapidly produced even for a few lines of code. This approach also allows the students' attention to remain focused on the topic in hand, without having to worry about the other areas necessary for a complete program.

Some parts of the workbook are designed to be used

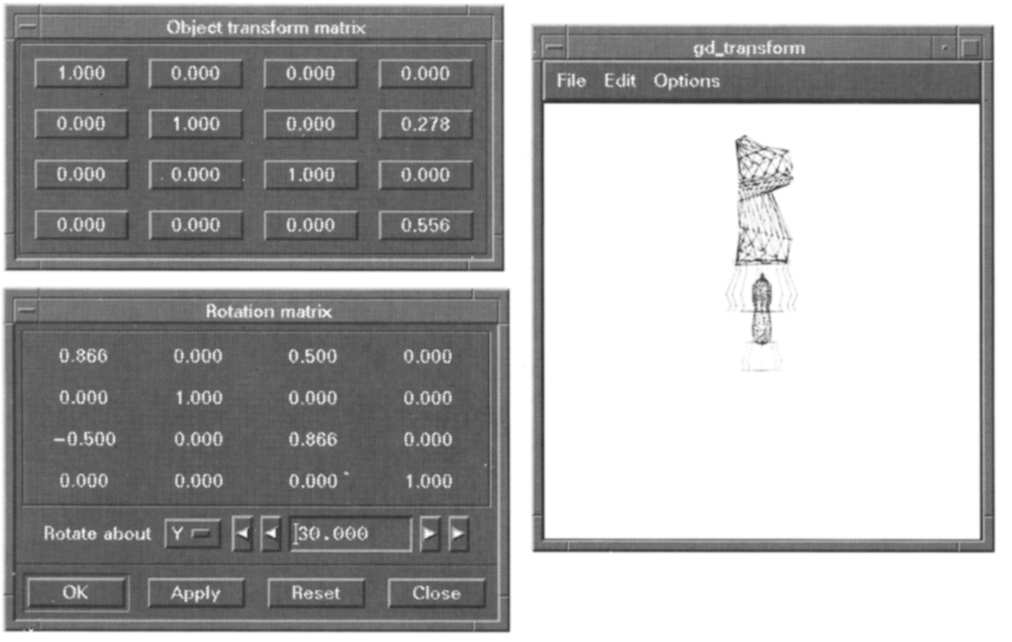

Fig. 2. An interactive program written for the Geometry module.

away from the computer, finding out facts about local practices or facilities, answering questions to force the immediate application of new knowledge. For example, having introduced the concept of primary colours, the borders of that concept are stretched and explored. Why use three primaries? What are the consequences of using only two? How would a system with four work?

A multiple-choice program is used to check comprehension of each section before progressing to the next. Not only does this mark the questions, it gives immediate feedback on each answer. This is either an explanation of why the answer is incorrect, or confirmatory details as to why it is correct.

5.4. *Going further*

Each module has a central theme or model that is used to give sufficient theoretical skeleton as a firm base onto which students can hang additional knowledge. A fine line has to be trod between excessive theoretical rigour and inadequate rules of thumb; between stultifying detail and a breezy overview.

Having hopefully provided this as the core part of the course, a resource list is supplied to enable particular areas to be developed either by the presenter or individual students. The contents vary between modules but typically it contains an annotated bibliography, descriptions of free or cheap software that may be obtained by FTP, usenet newsgroups, discussion lists, and other sources of on-line information pertinent to the topic, and references to other training materials that are available to the higher education community at moderate or no cost.

This provides an intermediate stage between reading the student notes and performing a literature search or delving through textbooks.

One problem with a printed resource list is that it can become out-of-date surprisingly quickly. This problem was felt to be especially acute in the field of Scientific Visualisation, prompting an exploration of possible alternatives when that module was under development.

Resource lists are now being supplied as electronic hypertext documents, using the World Wide Web (WWW). As the pages are held centrally at Manchester, they can be readily updated without the distribution problems attendant on traditional printed documents. Freely available WWW browsers, such as NCSA Mosaic, can be used to access the latest version of each page over the network from any Internet site. Figure 3 shows an example of this process.

Using a WWW server allows attractively formatted text, with still or moving colour images, to be delivered to any site in a platform independent manner. Links can also be made to FTP sites, gopher holes, and Wide Area Information Servers (WAIS) that are activated by simply clicking on them with a mouse. This is a substantial and valuable increase in ease-of-use, particularly for less "network aware" users.

5.5. *Distance learning*

As the writers of the material are not the presenters, there is a potential problem of lack of feedback. This has been addressed by including evaluation forms, which invite a two-stage process: students feed back to presenters, and presenters feed back to the authors. There is also an email address for comments and suggestions.

To encourage the students who are taught using these modules to comment, it is hoped to add an anonymous email "gripe" line, providing more direct channel of

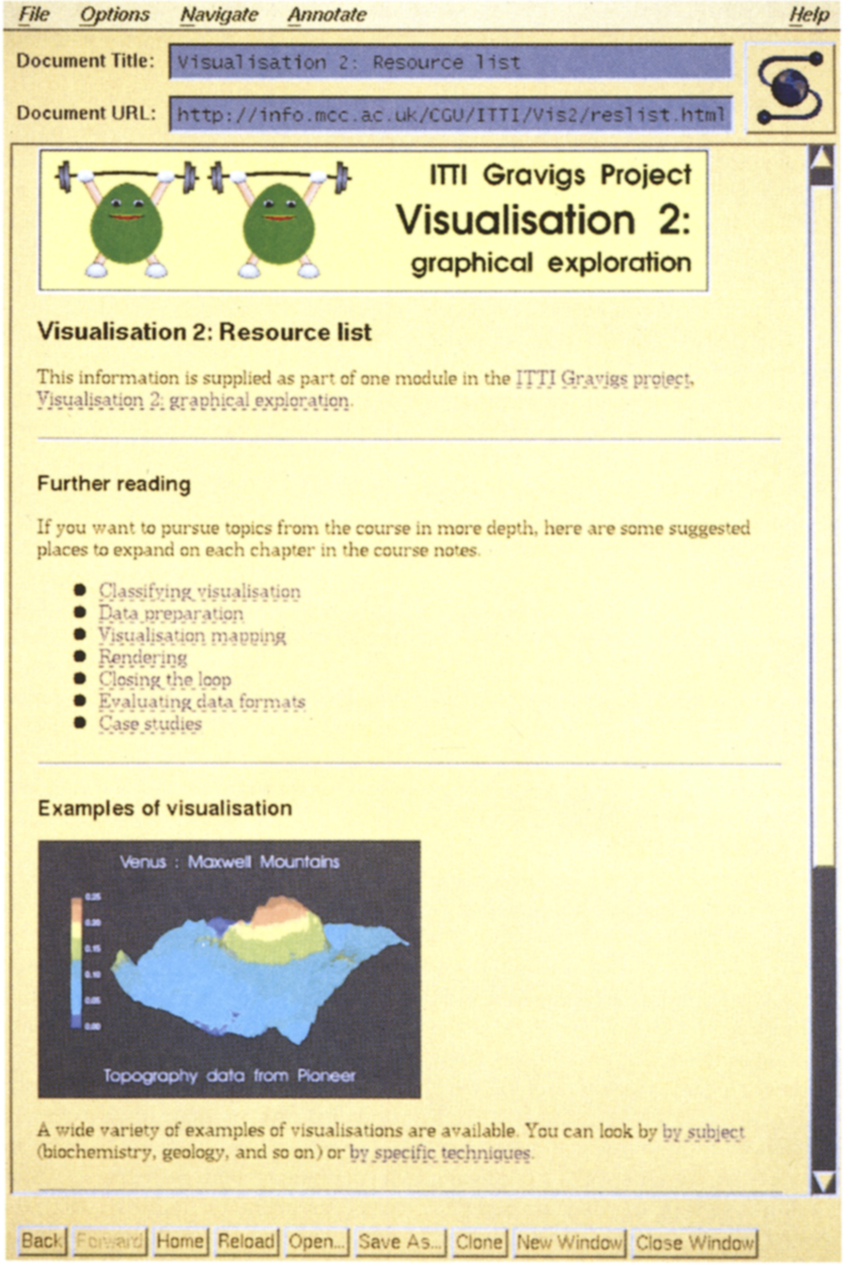

Fig. 3. Using NCSA Mosaic to remotely access resource material.

communication that is hopefully less intimidating to students. This will use an email anonymiser service in Finland.

To ensure that the materials are useful and usable, they are evaluated by the project team leaders and by selected third parties. Where possible, the draft versions of each module are used to present actual courses. The degree of uptake of each section of the material can be monitored, and sections that have been poorly understood can be redesigned.

Revisions are made in the light of the findings from this process before a module is released.

6. THOUGHTS ON WORKSHOP THEMES

6.1. *Computer graphics education*

It is moot whether there is a core of computer graphics knowledge that must be understood by all undergraduate computer science students. While the increasing importance of graphics cannot be denied, the explosive growth of computing in both depth and breadth means that a surprising degree of specialisation is required even at undergraduate level. Students tend to learn groups of related topics, tending for example towards hardware, or language theory. The question then becomes, what subjects fit along with computer graphics to form a rounded first degree?

Thought must be given to the sort of career path that is likely for those computer scientists who intend to specialise in graphics and seek a career in the field. Appropriate subjects to teach them can then be deduced from their probable requirements once working. Many will end up working for hardware companies or software vendors, helping to generate product. They will be implementors rather than users. To ensure a competitive advantage, the techniques they use will be innovative, and by implication not those that were taught at undergraduate level. Fundamental concepts and a rigorous theoretical background from which to develop new ideas are likely to stand them in good stead, as will experience of team working and an ingrained ethos of quality engineering. A general awareness of the *types* of algorithm that may be employed to produce a wide range of graphical effects will perhaps be more valuable than a more detailed knowledge of those techniques that are currently most common.

6.2. *Visualisation education*

Visualisation is an important tool whose area of applicability is steadily increasing. The traditional user base of engineers and hard scientists is being joined by converts from the soft and social sciences and the humanities.

Before asking what graphics knowledge is a suitable basis for visualisation education, we should perhaps consider the order in which these skills are acquired. In many cases, it will be visualisation first, perhaps followed by a need to understand some graphics as the limits of existing visualisation systems become restrictive.

The number of noncomputer scientists using graphics or visualisation is clearly much larger than the total number of computer scientists, let alone those of the latter who are specialising in graphics. It is clearly worthwhile to consider the particular needs of this large group.

A dangerous assumption is that teaching graphics to noncomputer scientists merely involves producing a summarised, diluted version of what is taught to computer scientists who are specialising in graphics. Rather, it is a difference of emphasis between those who will implement or modify graphics systems—the computer scientists—and those who will stretch those systems in an effort to get the results they need. Nongraphics professionals may require *more* detail and have more stringent requirements in certain areas. On the other hand, because they will not be implementing computer graphics algorithms, many details can be omitted; the audience need only know enough about a group of alternative methods to make an intelligent selection between them.

For example, someone doing research in computer graphics is often more interested in proof of concept and theoretical justification of their approach than in the end results. A view of a room may show a blue table sitting on a cyan floor with green walls because these colours are trivial to specify in RGB and the resulting image is of less importance than the elegant new algorithm that produced it.

On the other hand, engineers visualising the correlation of two variables in a simulation may need to be sure that the bivariate colour scale they are using is perceptually linear in both directions to avoid a false view of the data. Students of archaeology or architecture doing visualisation of interiors will require a knowledge of colour that is towards the leading edge of what is possible, as they specify the colour of walls from direct physical measurements of paint and fabric samples.

However, information such as alternative methods of adaptively tessellating an arbitrary curved surface, while fascinating and essential for the computer scientists, would be excess detail for the visualisers.

6.3. *Common issues*

Graphics design and aesthetics is an area that is barely touched upon in much graphics education. And yet it is an important issue; a skillfully rendered photorealistic image will look poor if the elementary rules of artistic composition have been ignored. The product of scientific visualisation is—or should be—increased understanding and enhanced communication rather than pretty but meaningless pictures, and borrowing skills from professions with a good historical record in graphical communication—graphics design, or cartography, for example—can certainly aid this process.

On the other hand, misapplication of artistic creativity in such fields as advertising and business presentation has produced graphs that range from misleading to meaningless. It is important that students be taught to recognise and avoid similar techniques in scientific visualisation where the scope for excesses is even greater.

Traditionally, computer graphics people have not bothered with existing artistic experience, and artists—if they used a computer at all—have seemed oblivious to computer graphics practice. It is anticipated that one consequence of improved communication between artists and scientists will be a diminution of inadvertent errors in graphical communication. The two camps are coming together as each realises a need for the others skills, yet there is a real danger that lack of communication and interdisciplinary training will result in a rapid overshooting rather than meeting in the common ground.

Recognising this, some effort has been made by the authors to include artistic and graphic design input in the training materials being developed. The first of the two visualisation modules (*Visualisation 1:* Graphical Communication) stressed the importance of good layout skills to produce an uncluttered and readily understood presentation of the data. Evaluators for the module on colour included a graphic artist and an arts teacher, and their particular inputs were most valuable.

7. CONCLUSIONS

A need for ready-to-use teaching materials for users of computer graphics and scientific visualisation has been identified. The training requirements of this class of users have been distinguished from those of traditional computer graphics specialists.

The type of delivery best suited to the target audience has been deduced, the components required for such a course have been examined and design decisions explored. A modular course of training materials has been developed in accordance with these principles and is being made available to the higher education community.

One final question, although perhaps uncomfortable to some, needs to be examined. To what extent does the availability of existing packages (such as CAD systems, geometric modelers, drawing tools) and flexible, customisable visualisation systems obviate the need for noncomputer scientists to ever use a graphics subroutine library? Should scientists be coding? There are no easy or universal answers to this question.