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Designing CBL Courseware for the Interactive Learning of Electronics Design

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In order to produce effective courseware it is essential to identify specific learning objectives at the outset of the project; it is important to apply a structured approach to the analysis of the skills students are to acquire through using the courseware. In this paper a technique is discussed and demonstrated which involves a hierarchical decomposition using a dictionary of overt verbs in order to refine the specification of the skills required. The decomposition is not always obvious and usually requires continual refinement with time and experience as the project proceeds. It also provides a method of auditing the project. Eventually individual skills or learning objectives are identified and task specifications developed to indicate how these may be achieved. From the decomposition a detailed storyboard is evolved which documents the contents of a series of frames that describe how these objectives are achieved in courseware. A number of frame types have been identified and their use is illustrated with an example from the courseware being developed by the authors.

INTRODUCTION

IN 1991 the Higher Education Funding Councils of England, Scotland, Wales and Northern Ireland initiated their Teaching and Learning Technology Programme (TLTP) under which they supported proposals from the universities which addressed the problem of making teaching and learning more productive and efficient through the use of modern technology. In June 1992 the Electronic Design Education Consortium (EDEC), comprising the UK Universities of Bristol, Essex, Huddersfield, Kent, Manchester, Newcastle, Oxford Brookes and UMIST, commenced a 3 year, £1M TLTP project to develop computer-based learning (CBL) courseware to support the undergraduate teaching of electronic design.

In October 1992 the first phase of dedicated staff were appointed and the detailed definition phase commenced. Authorware^{TM} Professional Version 2.0 from Macromedia® was selected as the prime authoring tool with Knowledge Pro^{TM} for windows® used for some additional material. The standard platform for delivery of the material is a 50 MHz (or faster) 486 PC, with at least 8 Mbytes of RAM, a 500 Mbyte hard disk, SVGA monitor (800 × 600 pixels and 256 colours), 8 bit Soundblaster^{TM} Card and a CD-ROM or Internet access for distribution of the CBL material.

The project identified four main themes for which CBL courseware was to be developed:

- electronics circuit design;
- digital design;
- systems design;
- testing and design for test.

This paper describes the courseware development philosophy formulated by the authors at the University of Essex, for the production of their courseware for themes A and B. The application of this top-down, structured philosophy is demonstrated using examples from the authors' courseware. Frames from the resulting courseware are illustrated using screen shots.

A CBL DESIGN PHILOSOPHY

Aims

In order for CBL courseware to provide an effective method for student learning the authors believe that the student must be very actively involved when using the courseware. A conventional page-turning electronic version of a textbook does not provide a good model for the student learning process. Therefore our first task was to design and agree a flexible, attractive navigation framework within which our courseware would be developed. The framework was evaluated by students in a local trial and their comments, together with those from other

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consortium members, were considered during the production of a revised framework, which has now been re-written in C for increased speed and is used throughout the consortium to provide a consistent student interface. The framework allows the courseware to be divided into chapters and sections, and provides facilities for the academic user to re-configure the courseware to his individual course requirements, by changing the order of presentation or by leaving out particular sections or chapters. In addition, the student can readily navigate to a particular chapter or section. It is possible to include notes and to set *bookmarks* in the courseware to enable rapid return to selected points in the material. Students are encouraged to keep their own notes directly using a word processor running in a separate window, in some modules in an electronic log book or by hand in the printed workbook which supports the particular module of courseware.

Early in the project those aspects of the teaching of electronic circuit and system design which could benefit from the use of CBL were identified. If the courseware provides an effective self-paced learning experience for the student, some formal lectures can be replaced partially or totally. There is also considerable potential for CBL to support a student's preparation for hardware and CAD laboratory experiments, and projects by introducing the methodology and showing how equipment can be used. In the case of problem-solving exercises courseware simulations of worked solutions can be produced to show students, through appropriate interactions, how a solution has been achieved. Computer-based evaluation of the student's understanding of a particular topic is used to provide the student with immediate feedback for self-assessment purposes. The results of these tests are not used for student assessment, although usage statistics can be logged and questionnaires used to obtain student comments on the CBL material.

Overview

An educational environment that uses computer-based learning material must incorporate the extensions to traditional teaching methods that this medium offers. The authors believe that the adoption of a structured courseware development methodology facilitates the creation of material that is both educationally effective and justified in terms of its use of the computer as the teaching medium. Our objective is to make full use of current multimedia technologies by the inclusion of appropriate still images, captured video, animation and sound to provide a motivating and thought-provoking experience, which goes beyond conventional workbook exercises [1].

The methodology begins by formulating a *high-level skill description* which is worded in terms of what the user will be able to do on successful completion of the learning programme. This provides a basis for implementing a *skill analysis* which is effectively a hierarchical decomposition of the high-level description of the skill into a number of separate skills by successively focusing its description. Eventually a level of skill definition is reached where a task specification can be written defining the requirements of the CBL module. From this task specification a detailed *storyboard* can be written describing the textual and graphical contents of the courseware *frames* which are to be implemented by the courseware author. The technique adopted for implementing the storyboards is based upon a method discussed by Hudson [2]. In this approach the *frame* consists of text and graphics and is directly related to a page of courseware.

Staff contribution

The high-level task description and subsequent decomposition are defined by the primary academics, who have a broad understanding of the overall course requirement, working in consultation with the author, who carries out the detailed development and implementation of the courseware. As the decomposition progresses the authors contribute more to the definition of the specific educational aims of each frame. Often as non-experts in the field they ask similar questions to a student and this enables the selection and scheduling of learning objectives to be realistically created and clearly specified. The detailed implementation using storyboards is the responsibility of the author, but is discussed and agreed with the primary academics before being implemented using the authoring language. A limited number of iterations of the detailed implementation are allowed to take place as ideas are tried and modified. After an agreed period the development of the module is frozen, whereupon it is made available to members of the consortium for evaluation and comment. Wherever possible this evaluation phase includes use by students in order to obtain their views on its usability and content. Comments are collated and any revisions which are agreed are incorporated into the module by the author as appropriate.

SKILL ANALYSIS

In a large courseware project it is important to maintain the general contextual relationship of the learning objectives which are defined in order that the user achieves particular skills. To achieve this the authors have adopted a graphical method of representing the decomposition of skills which is considered fundamental to our approach. This has strong links to Jackson's approach to structured design [3, 4] and is best explained using an example.

Example of skill analysis

Theme B of the EDEC project is concerned with developing courseware which will enable a student

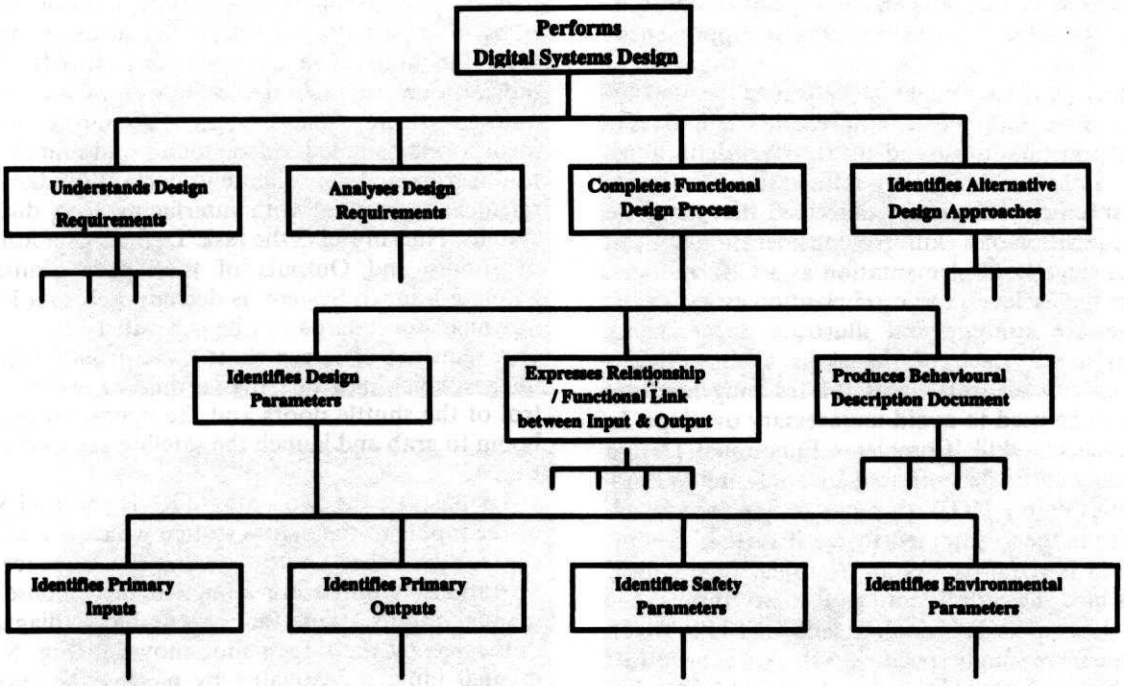


Fig. 1. Top levels of decomposition.

to acquire the skill to perform the design of digital systems. 'Performs Digital Systems Design' is therefore a statement of the ability that a student is to demonstrate on completion of all modules of the Theme B courseware. This is a WHAT requirement at the top level of the hierarchy. The next level defines the skill requirements which should be achieved in order to achieve the level above. In other words, it indicates HOW this objective is to achieved but also defines the WHAT that is required of the current level. Thus in Fig. 1 the second level indicates that the first level skills (assuming an inherent left to right precedence) include 'Understands Design Requirements', 'Analyses Design

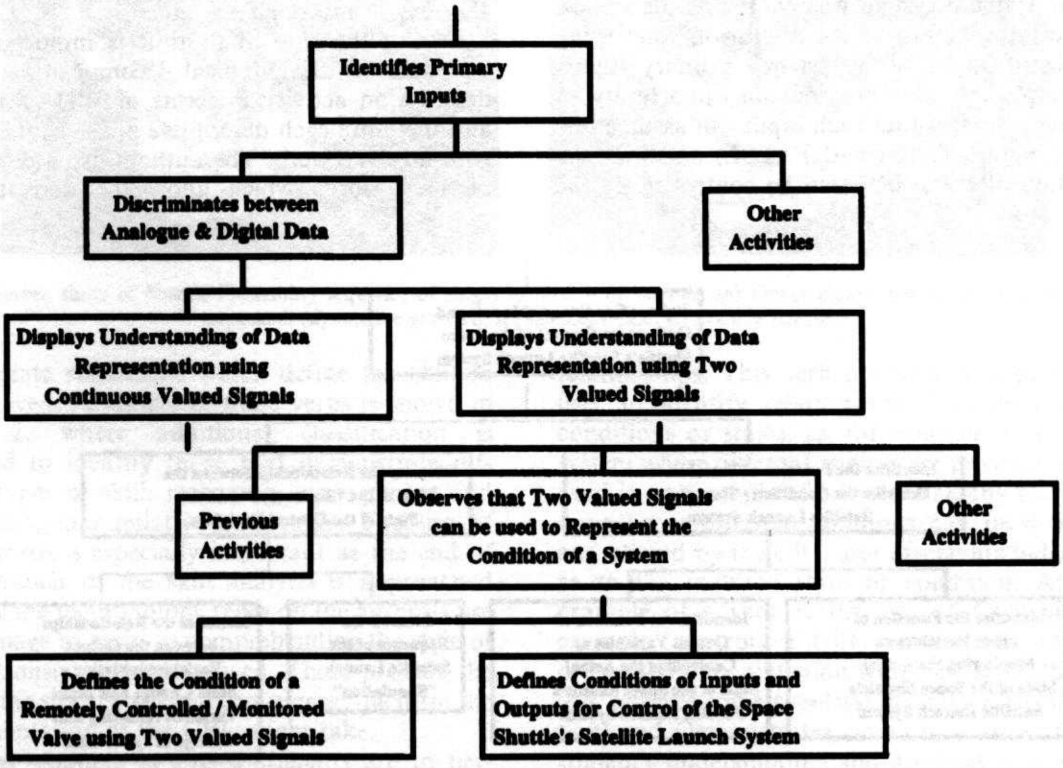


Fig. 2. Further decomposition.

Requirements', 'Completes Functional Design Process', 'Identifies Alternative Design Approaches', etc.

These skill requirements can each be decomposed into a number of requirements as indicated by the example third-and fourth-level definitions. These skills are recursively refined until realizable task specifications can be described that facilitate the acquisition of a skill. No consideration is given at this stage to implementation as a CBL module.

The higher levels of decomposition establish the courseware strategy and illustrate dependencies within areas. Each of the skills at these levels may specify separate areas for teaching modules and can be used to avoid unnecessary overlaps. In this case the skill 'Completes Functional Design Process' can be decomposed by analysing WHAT activities define HOW this can be achieved. Each activity is then examined to see if further decomposition is required. As an example, Fig. 2 illustrates how the skill 'Identifies Primary Inputs' has been decomposed through a series of skills which become increasingly specific. In this case the lowest level has suggested the tasks which will be used in the CBL module.

The number of levels of decomposition that are required is determined by the complexity of the skill defined at the highest level in the hierarchy. A complex skill such as 'Performs the task of Digital Systems Design' requires that decomposition is recursively performed until the many skills required of such a designer have been clearly identified. It is only at lower levels that the specific learning objectives of a CBL module can be defined. In this CBL module a particular application of a digital system was chosen as the vehicle for the introduction of the discussion concerning the identification of a system's primary inputs and outputs. It also provides an opportunity to introduce the fact that each input can assume one of two states (TRUE and FALSE) and that the operation of the system can be controlled by the logical values of individual inputs and combinations of inputs (at this stage the ideas of basic logic functions have not been introduced). The motivational interaction selected was the launch of a satellite from a Space Shuttle. This allowed us to incorporate sampled video, sound and animation to illustrate and consolidate important fundamental ideas associated with interfacing to a digital system. Thus in Fig. 3 the task 'Defines Conditions of Inputs and Outputs of the Space Shuttle's Satellite Launch System' is decomposed to a level at which storyboards can be generated.

A sequence of screen shots taken from a clip of images which illustrate the various stages of control of the shuttle doors and the operation of the boom to grab and launch the satellite are shown in Fig. 4.

To illustrate the two states (TRUE and FALSE) of the inputs to the digital system which is used to control the Space Shuttle system, the sequence of operations required are animated in response to manual inputs using the system block diagram illustrated by the screen shot shown in Fig. 5. A manual input is instigated by placing the cursor over a button below the animation window and pressing the left-hand mouse button. The Satellite Release Control system will generate appropriate control signals to activate an action within the shuttle. At the completion of the desired action within the shuttle, changes take place in the signals derived from the shuttle which act as inputs to the digital system. For example, when the shuttle doors have been opened DOORSOPEN is TRUE and this allows the boom to be unpacked.

Wording of tasks and sub-tasks

During the skill analysis it is important that each item in the graphical decomposition should describe an activity in terms of WHAT is done and therefore each descriptive phase should begin with an overt verb. The authors use a dictionary of such words which allow the derivation of

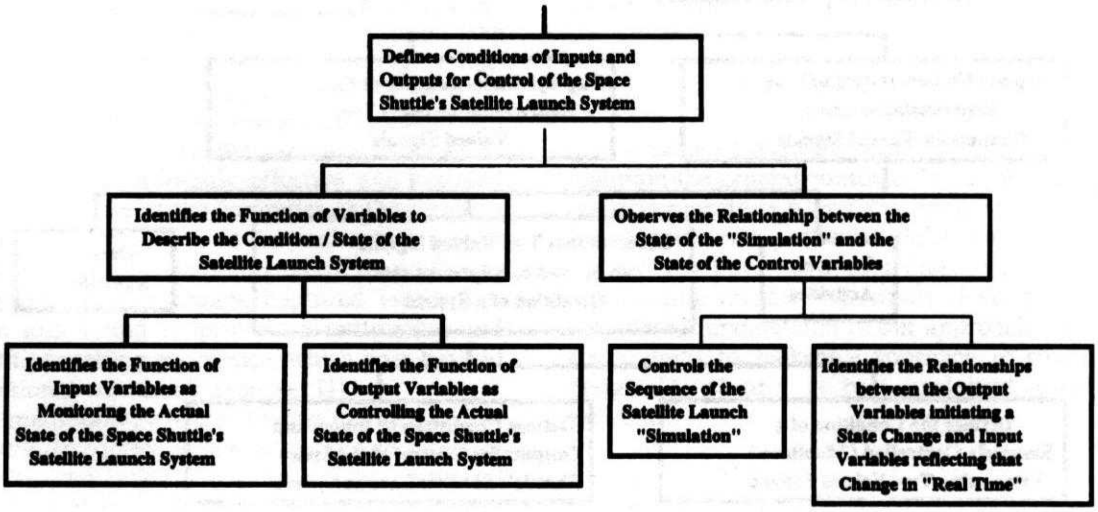


Fig. 3. Further decomposition to learning objectives.

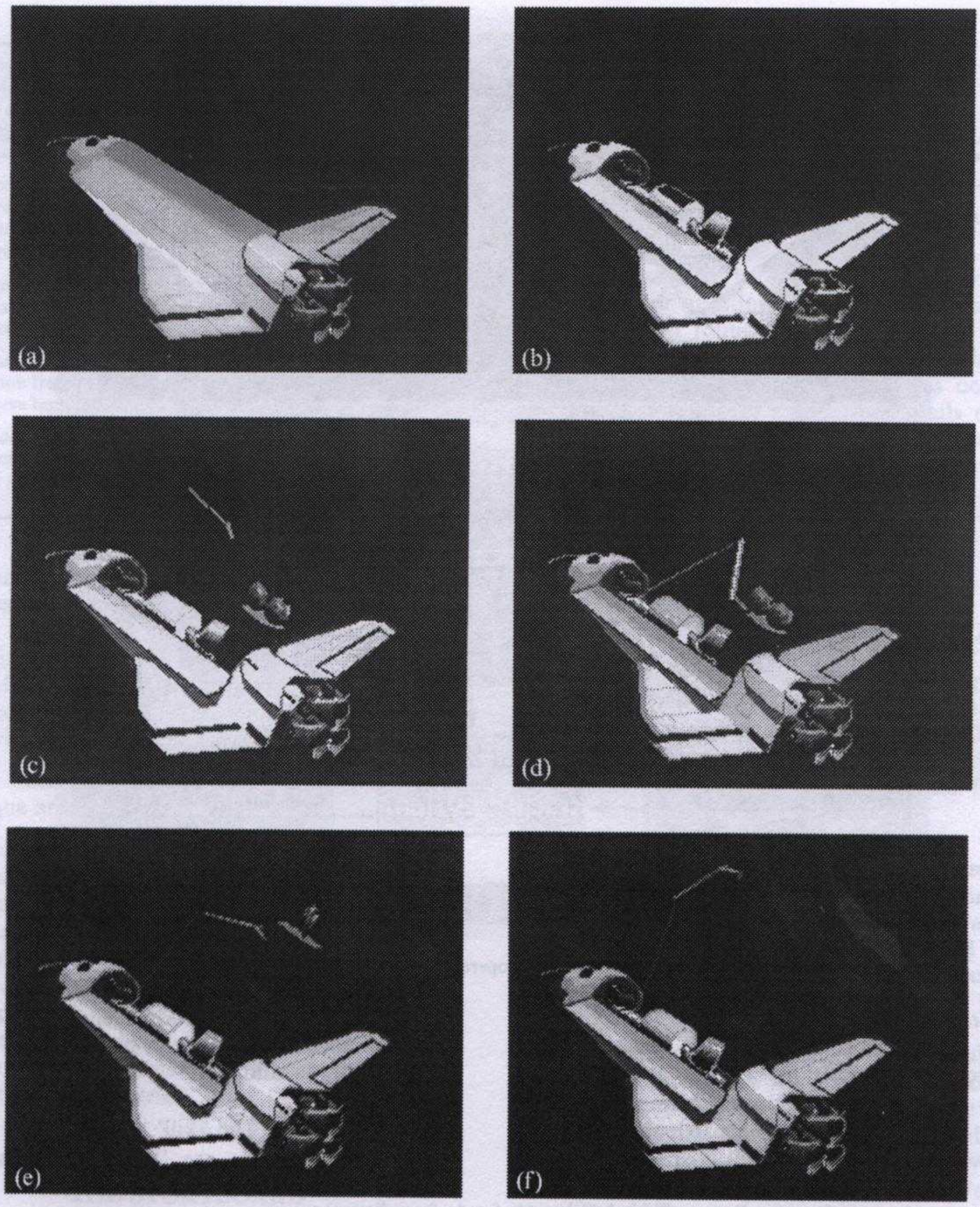


Fig. 4. Screen shots of Shuttle illustrating sequence of stages in release of satellite. (a) Doors closed; (b) doors open; (c) boom unpacked; (d) satellite grabbed; (e) satellite raised; (f) satellite released.

appropriate statements which define the skill to be achieved. A sample of these verbs is shown in Table 1, where additional classification is included to identify those that demonstrate different types of skill: reasoning, management and diagnostic, manipulative and value. The use of these words is especially important as the end of each branch of the skill analysis is approached because the methodology relies on the author's use of language to assist in comprehending the style of interactions(s) to be produced. These provide the link to the storyboard and can suggest the form the implementation of the CBL might take.

In the example in Fig. 3 students are to perform an activity that requires them to identify relationships. This verb points to a need for the user to identify relationships between different conditions or states, as, for example, in a digital system where different choices are possible. Such a need is an example of schema whereby the use of opposite or different solutions can be displayed and altered by the CBL user displaying judgement as to the required state or condition. Another example of a verb is the use of Controls (for example, controls a CBL simulation), which is often used in conjunction with the verbs Observes [e.g. observe some events(s) during a CBL simulation] and Demonstrates, so as to ensure that the student's understanding and progress is externally visible.

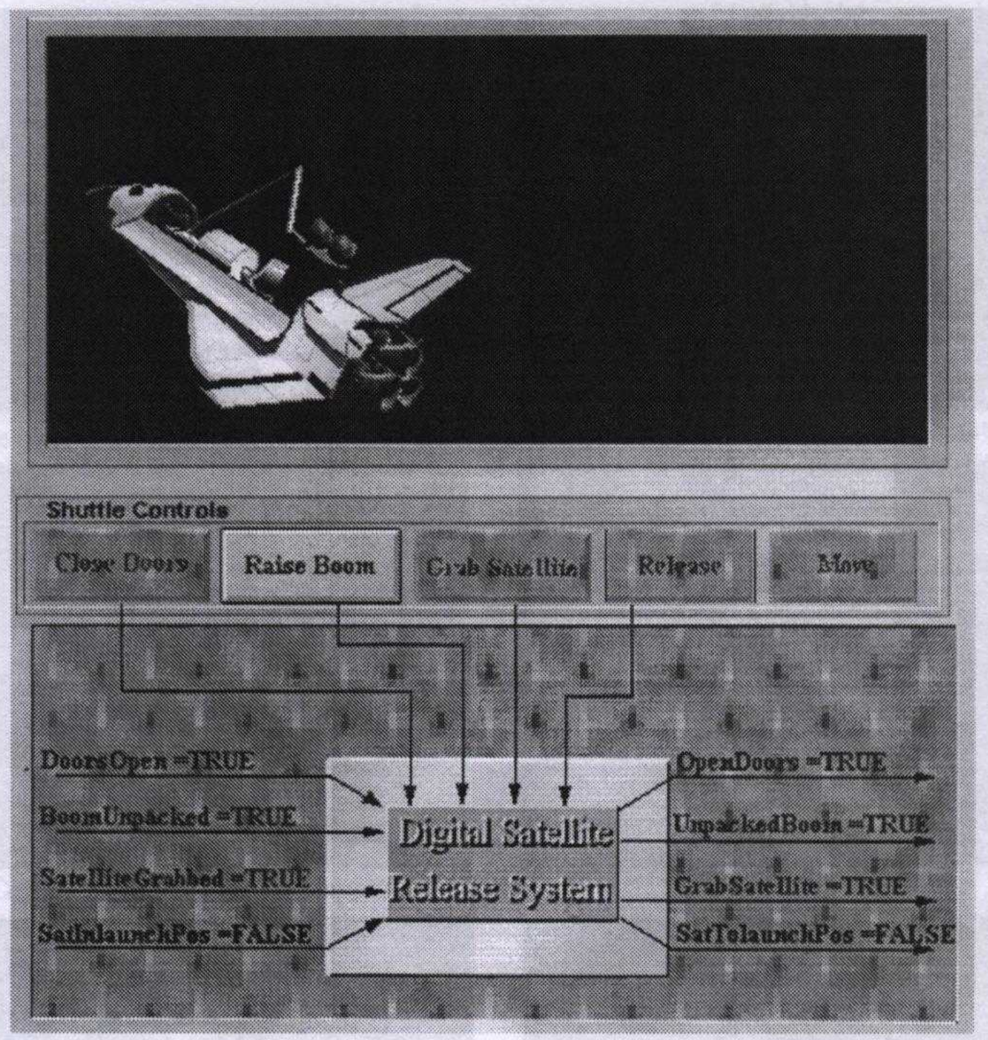


Fig. 5. Screen shot illustrating operation of satellite release system.

Benefits

The perspective of individual levels of the graphical decomposition changes as the viewer moves from higher to lower levels. At the top level it is oriented towards a particular ability or skill, whereas at lower levels it is oriented towards specific learning objectives which enable the skill to be acquired. These levels can be described under the following headings:

- The top level is 'The Skill'.
- Intermediate levels are 'Enabling Skills' that

Table 1. Selection of verbs from dictionary

Examples of reasoning skills:	Examples of management & diagnostic skills:	Examples of manipulative skills:	Examples of 'value' skills:
Annotates	Allocates	Activates	Abstracts
Assembles	Analyses	Aligns	Accumulates
Applies	Assigns	Carries Out	Alters
Arranges	Compares	Centres	Avoids
Communicates	Controls	Checks	Chooses
Completes	Defines	Connects	Combines
Correlates	Employs	Couples	Completes
Catalogues	Exacts	Disengages	Complies
Demonstrates	Forecasts	Distributes	Conforms
Derives	Identifies	Empties	Selects
Employs	Specifics	Intersects	Specifies
Organises	Solves	Prepares	Resolves
Recovers	Tests	Reassembles	Revises
Tabulates	Updates	Slots	Theorises
Transfers	Verifies	Withdraws	Verifies

Table 2. Frame definitions

The M frame.
The Motivation frame will always be the first frame in a group and provides the student with an objective for the coming frame sequence. The M frame contains textual and graphical information.

The I frame.
The Information frame imparts or recalls knowledge but does not test understanding. The I frame contains textual and graphical information and may have interactions.

The E frame.
The Experimentation frame provides the student with an interaction allowing the investigation of causes and effects.

The L frame.
The Link frame provides an association between concepts that have been introduced in previous frames.

The T frame.
The Test frame provides the student with an interaction to enable self-determination of understanding.

support the acquisition of 'The Skill'. These may be decomposed by further 'Enabling Skills'.

- The lowest level addresses the 'Basic Skills' required to achieve 'The Skill' and defines the specific learning objectives, which are used by the courseware author in the production of the storyboard, as detailed in the next section.

The main benefits gained from using this technique are:

- The definition of the skill and its decomposition is clearly defined and can therefore be amended and agreed upon by all concerned.
- It successively decomposes the skill so that learning objectives can be readily derived.
- It provides a focus for authors and courseware design teams.
- It acts as a management auditing tool.
- It provides a fundamental link between the skills and the CBL material.

THE STORYBOARD

Introduction

The storyboard provides the detailed description of the learning objectives which are realized in the courseware. It fulfils three major functions: (i) it promotes rapid interchange of ideas before detailed courseware production; (ii) it provides a mechanism for auditing the types of interaction; and (iii) it is a foundation document for information transfer to future presentational tools. The storyboard consists of a set of frames defining user interaction together with the details of the accompanying text, graphics and sound. Graphics includes still pictures, video clips and animation sequences. Frames are classified into five types reflecting the learning function and the level of interaction as indicated in Table 2.

Table 3. Structure of a typical frame chart

	1 2 3 4 ⋮ N	Frame number within current section
Workbook Entry Type	⋮	Workbook Entry Frame type [M/I/E/L/T]
Concept 1	⋮	Concept 1 frames
Concept 2	⋮	Concept 2 frames
⋮	⋮ ⋮ ⋮ ⋮ ⋮	⋮
Concept *n*	⋮	Concept *n* frames

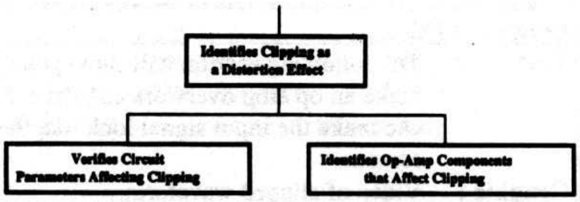


Fig. 6. Learning objectives for clipping example.

The storyboard structure

The storyboard has two main sections, the *frame chart* and the *frame descriptions*. The frame chart provides the author with a record of the sequence of frames within a section of the CBL material, and takes the general form shown in Table 3. The frame description provides a textual explanation of the graphics, text and interactions for each frame.

Storyboard generation—the first iteration

Storyboard development is an iterative process. Firstly the author produces a storyboard containing only the *M frame* and the *I frames*. This allows the approval of the basic concepts that need to be introduced without the need for lengthy discussion about the interactions and test that need to be incorporated.

To illustrate the generation of a storyboard an example is taken from a particular part of the graphical decomposition associated with the CBL material describing clipping in operational amplifiers. This is illustrated in Fig. 6. The first iteration of the *frame chart* for the section which 'Verifies Circuit Parameters Affecting Clipping' is shown in Table 4.

Initially only three frames are identified—an M frame to motivate and two I frames to introduce clipping and to indicate that the desired circuit gain, the input signal level and the power supply voltage are all parameters which can affect whether the circuit produces a clipped output.

Table 4. First iteration of frame chart

	1	2	3
Workbook Entry			
Type	M	I	I
Clipping	✓	✓	
Gain			✓
Input			✓
Supply			✓

***Frame 1* : [M]**	
Text :	The following section will show you one of the interesting distortion effects that trying to make an op amp overwork can have. By the end of this section you will know how a circuit can make the input signal look like the output signal. When you are ready go to the next screen.
Graphic :	Video of clipped waveform.
***Frame 2* : [I]**	
Text :	The effect you have just seen is called Voltage Amplitude Clipping or Voltage Saturation.
Graphic:	None.
***Frame 3* :[I]**	
Text :	The GAIN of a circuit, the INPUT amplitude and the POWER supply all affect whether or not a circuit will SATURATE. Power supply Input signal amplitude Gain of the circuit
Graphic:	Picture of pig being dowsed with water.

Fig. 7. Frame description for first iteration of the storyboard.

The √ indicates that the particular concept is to be addressed in the frame indicated. The number of entries in a particular column indicates the number of concepts which are to be addressed in that particular frame. Therefore this chart provides a convenient method for auditing the number of new concepts being introduced in a frame to avoid overloading. The *frame description* details the contents of each frame and is shown in Fig. 7.

Storyboard generation—the second iteration

Having decided that the basic concepts are correct, the author adds the interaction and test frames. Following the *clipping* I frame (frame 2), a T frame (a new frame 3) is added to test understanding by using a simple interaction (Fig. 8). The second I frame (now frame 4) is similarly tested and a new frame 5 introduced to test the understanding of the previously acquired concept of gain within the current context (see Fig. 9). Within the text in these frames some words are shown { }; this identifies that a textual response is expected. Words within [ ] identify an additional button on the screen to those normally shown for navigation. With the three elements which can contribute to clipping introduced, the user is encouraged to examine the effects that each has on the output of the circuit using an E-frame (new frame 6) as described in Fig. 10.

Having introduced all the concepts and allowed the user to experiment, a link frame (frame 7), as shown in Fig. 11, is added to reinforce the connection between the three ideas.

The second iteration frame chart is shown in Table 5. Subsequent iterations of the storyboard rely on field trials of the course material. As areas of deficiency are identified the author can quickly ascertain where to add or delete material, and even change its nature. A sequence of screen captures developed for this particular storyboard is shown in Fig. 12.

***Frame 3* : [T]**	
Text :	The circuit below is exhibiting a type of signal distortion described as voltage .... 1) C{lipping} or 2) S{aturation}. Fill in the blank spaces. To select an item click on it or press the number on the keyboard. You have N tries at this question.
Graphic :	Amplifier model with oscilloscopes on input and output. 2 text response areas corresponding to each answer required.
Response :	Wrong : Flash the message "WRONG!!" Correct : Flash the message "CORRECT!!"
If wrong :	
	Tries<N : decrement N and continue. Tries=N : display "You have had too many tries. The correct answers are shown"[Continue], fill in the text responses.
If all correct :	
	display "Well done, you have all the answers correct"[Continue]

Fig. 8. The new T frame (frame 3) introduced after I frame 2.

***Frame 5* : [T]**

Text : Shown below is a non-inverting op amp circuit. If you changed R2 from 1k to 9k then the GAIN of the circuit will I{ncrease}. You have N tries at this question.
Graphic : circuit board, variable resistor and circuit diagram of non-inverting op amp circuit.
Response : Wrong : Flash the message "WRONG!!"
Correct : Flash the message "CORRECT!!"
If wrong :
Tries<N : decrement N and continue.
Tries=N : display "You have had too many tries.
The correct answer is INCREASE"[Continue].

Fig. 9. The new T frame (frame 5) introduced after I frame 3.

***Frame 6* : [E]**

Text : Shown under this message is a test set-up for you to examine the effects that changing the gain, power supply and input amplitude have on the output of the circuit. Try experimenting with the Power Supply, the Variable Resistor (to change the gain) and the Signal Generator (to change the input amplitude). When you are ready to try the experiment click on this message to remove it. When you have finished experimenting go to the next screen.
Graphic : Signal Generator, Circuit Board, Power Supply, Oscilloscope, Variable Resistor.
Interaction : When the message is clicked on remove it.
As the student changes the settings plot the output on the oscilloscope.

Fig. 10. The new E frame (frame 6).

***Frame 7*: [L]**

Text : REMEMBER voltage SATURATION or CLIPPING is affected by ....
Power Supply
Input signal amplitude
Gain of the circuit
Graphic : Picture of pig being dowsed with water.

Fig. 11. The new L frame (frame 7).

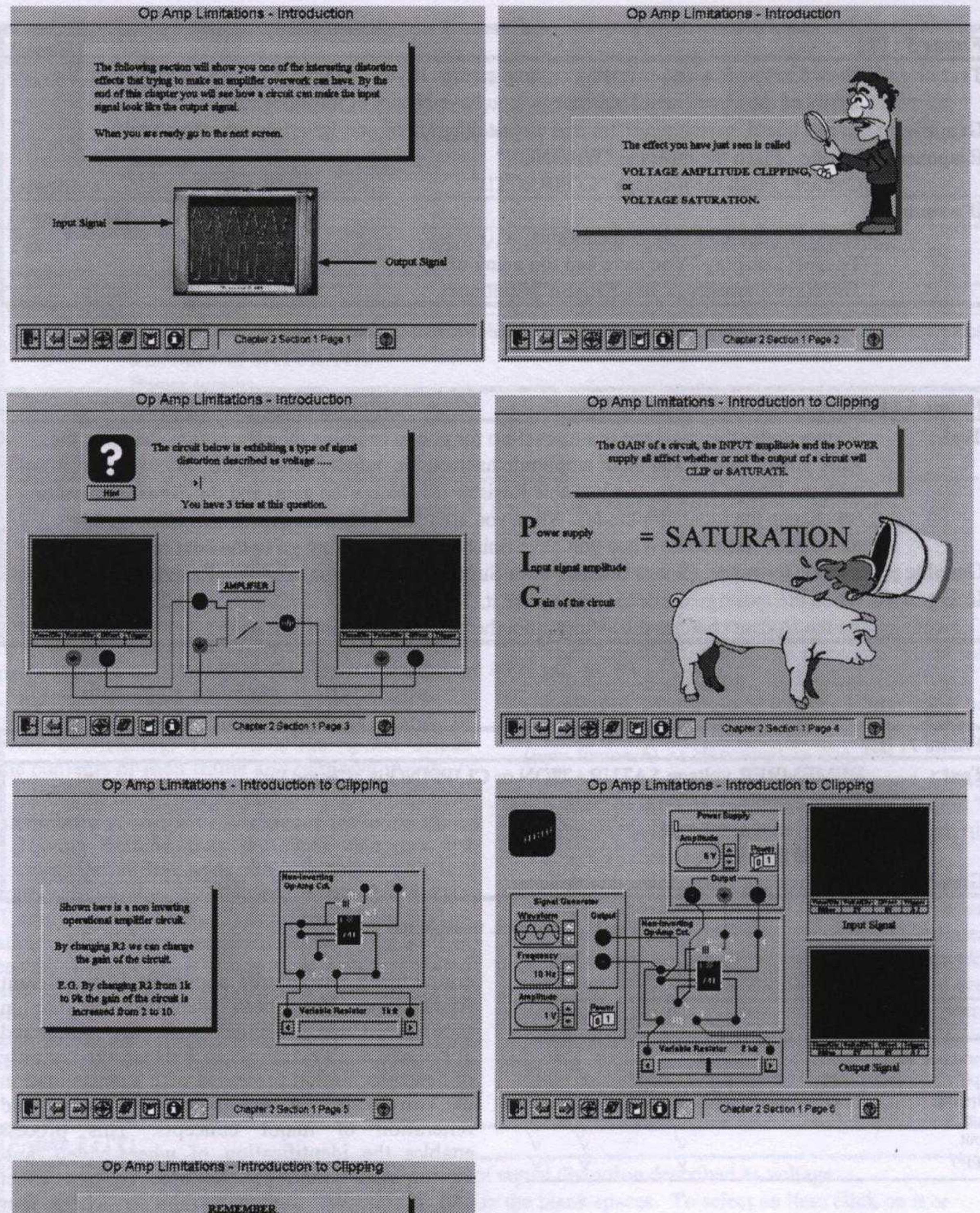
Table 5. Second iteration frame chart

	1	2	3	4	5	6	7
Workbook Entry							
Type	M	I	T	I	T	E	L
Glipping	√	√	√	√			√
Gain				√	√	√	√
Input				√		√	√
Supply				√		√	√

CONCLUSIONS

This paper describes a top-down structured approach for the development of computer-based learning material for the teaching of electronics design. A skill analysis is performed using a graphical chart to display the relationship between the skills that are expected to be acquired as they are hierarchically decomposed. The use of overt verbs enables the description of activities and the production of low-level task specifications and learning objectives. At this lower level detailed storyboards for the courseware modules are generated using a structured approach. Five different frame types have been identified for use in modules. These, together with the structured approach, enable authors to balance the quantity of new information presented with a consolidation of knowledge via self-assessment testing and reiteration of major concepts. This process enables the identification of where video, animation and sound can be used to best effect and allows the author to specify where user interaction is necessary. During this process it becomes clear whether the particular low-level learning objectives identified in the skill analysis will benefit significantly from being supported by computer-based learning. As a result of using the approach described in this paper the authors have successfully developed courseware to support the teaching of electronics design, in particular analogue and digital design.

The CBL material that has resulted from the EDEC project is now being used within the participating universities. The material completed during the duration of the project is available to other UK universities and it is intended that in the



Op Amp Limitations - Introduction

The following section will show you one of the interesting distortion effects that trying to make an amplifier overwork can have. By the end of this chapter you will see how a circuit can make the input signal look like the output signal.

When you are ready go to the next screen.

Op Amp Limitations - Introduction

The effect you have just seen is called

VOLTAGE AMPLITUDE CLIPPING,
or
VOLTAGE SATURATION.

Op Amp Limitations - Introduction

The circuit below is exhibiting a type of signal distortion described as voltage .....

You have 3 tries at this question.

Op Amp Limitations - Introduction to Clipping

The GAIN of a circuit, the INPUT amplitude and the POWER supply all affect whether or not the output of a circuit will CLIP or SATURATE.

Power supply
Input signal amplitude
Gain of the circuit
= SATURATION

Op Amp Limitations - Introduction to Clipping

Shown here is a non inverting operational amplifier circuit.

By changing R2 we can change the gain of the circuit.

E.G. By changing R2 from 1k to 9k the gain of the circuit is increased from 2 to 10.

Op Amp Limitations - Introduction to Clipping

Op Amp Limitations - Introduction to Clipping

REMEMBER.

voltage SATURATION or CLIPPING is affected by .....

Power supply
Input signal amplitude
Gain of the circuit
= SATURATION

Fig. 12. Sequence of screen captures for clipping example.

future it will be licensed for use outside the UK. For the current status of the project access our World Wide Web server at UMIST using the address http://edec.brookes.ac.uk/.

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Rob Massara is Head of Department and acted as Leader of Theme A (electronic circuit design) of the EDEC project. His particular interests are concerned with analogue integrated circuit design, computer aids to integrated circuit design and optimization techniques. He was responsible for defining the topics covered by Theme A and coordinating the contributions of the individual academic consultants to Theme A within the participating universities as well as contributing to the particular modules developed at Essex.

Peter Noakes is a Senior Lecturer with a particular interest in digital system design, VLSI design and neural networks. He acted as the Essex academic consultant to Theme B (digital design) of the EDEC project and was responsible for defining the academic content and learning objectives of the Theme modules produced at Essex.

Bob Mack is also a Senior Lecturer and was an academic consultant to Theme A. His interests include analogue integrated circuit design and design automation tools for analogue IC. He was responsible for defining the academic content and learning objectives of the Theme A modules produced at Essex.

Mark Franklin was a Research Assistant who worked within Theme B for 2 years. He contributed to the C version of the EDEC navigation framework and was responsible for developing a number of digital design CBL courseware modules including number systems, design methodology and finite state machine design. He is joining CBL Technology Ltd. in Derby, UK as their Training Manager.

Nick Gustard joined the EDEC project for 15 months as a Research Assistant within Theme A after completing his PhD studies. He worked on a number of modules concerned with electronics circuits, including TTL and CMOS circuits, fault finding and operational amplifier non-idealities.

Phil Smith joined the EDEC project shortly after it began, having worked as a design engineer for GEC Marconi Electronics. He developed the Authorware version of the EDEC navigation framework and developed Theme A modules on operational amplifier slew rate and saturation characteristics and an early version of the fault finding module. After a year he left to join CBL Technology LTD in Derby, UK as their Systems Development Manager.