An Interactive Computerized Multimedia Tutorial for Engineering Graphics Instruction

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ABSTRACT

A multimedia tutorial has been developed as a learning aid for a freshman engineering graphics course. The tutorial is designed to assist in visualizing the principles of engineering graphics including orthogonal projection, sectioning in engineering drawing, geometric dimensioning and tolerancing, and the geometric relationships involved in descriptive.geometry A combination of 3-dimensional (3D) images, animation, and audio narration explain many of the basic principles of engineering graphics that may be difficult to describe with text and still images alone. Interactive example problems, with solutions, that parallel the course lectures and assignments are also included. These examples provide step-by-step solutions to traditional graphics.problems, explaining at each step the proper procedure to reach the solution. Students can review the material at their own pace, moving backward or forward as necessary. Multimedia tutorials in engineering graphics have been used at U.C. Berkeley for four years.

Introduction

Computerized multimedia software (multimedia) has brought audio, video, and interactive user interfaces to the personal computer. Engineering educators are now realizing the potential of multimedia as a learning and teaching tool. Educators who are experimenting with various multimedia instructional aids include Rais-Rohani and Young (1996), Ressler (1996), Agogino and Evans (1993) and Lipman and Lieu (1994).

At the University of California at Berkeley (U.C. Berkeley), a multimedia tutorial has been developed that focuses on engineering graphics. The tutorial, entitled *Graphics Interactive*, is intended to be a learning aid that supplements the textbook and lectures in a freshmen engineering graphics course. The topics covered include, among others, the principles of orthographic projection, sectioning in engineering drawings, geometric dimensioning and tolerancing, and descriptive geometry. Much of the effort in developing the tutorial was concentrated on using the tools provided by multimedia to aid 3-dimensional (3D) visualization through animation, focus the user on graphics rather than text through audio narration, and promote learning by association through interactive user interfaces.

The tutorials were authored using Asymmetrix ToolBook™. The animations were created using Autodesk's 3-D Studio™. Currently, the tutorials are offered to students in the form of compact disks (CD's) that the students may run on their own personal computers or on the personal computers provided by the University in the engineering graphics laboratory. The graphics laboratory provides 90 MHz Pentium™ processors with 16 megabytes of RAM, quad-speed CD-ROM drives, and 16 bit color video displays. This system, operating under Windows 95™, is the recommended minimum system configuration for the tutorial. The absolute minimum system configuration is a 80486 DX processor with 8 megabytes of RAM, a double-speed CD-ROM drive, and 8 bit color operating under Windows 3.1. The minimum required hard-drive space is 6 megabytes.

Tutorial Content

A table of contents for the tutorial is shown in *Figure 1*. The *Introduction* chapter gives students some historical perspective, briefly showing how engineering has evolved and indicating places where engineering graphics has been or could have been useful. It also lists the main functions of engineering graphics in modern engineering. The *Sketching* chapter presents fundamental sketching techniques, illustrating how to quickly generate clear sketches that communicate the form and function of devices. Step-by-step examples show the development of several sketches. The next two chapters discuss the basics of engineering drawings. The *Formal Drawings* chapter presents the general format of engineering drawings, explains the purpose of each region on such drawings, and defines terms associated with engineering drawings. The *Orthogonal Projection* chapter presents the basic theory of orthogonal projection and shows how it is used to create standard views and auxiliary views in engineering drawings. The *Pictorials* chapter defines isometric, oblique, and perspective views and shows how they differ. Examples demonstrate how they are constructed. The *Sections* chapter discusses the construction of section views in engineering drawings and the conventions used in their construction. The *Dimensioning* chapter gives guidelines to promote good dimensioning practices, and defines terms and common shorthand found in engineering drawings. The *Tolerancing* chapter presents geometric tolerancing guidelines. It covers tolerances associated with common production methods, fits, datums, true position tolerancing, and the maximum material condition. The final chapter in the tutorial covers descrip-

1.0 Introduction
- **1.1 Objectives**
- **1.2 History**
- **1.3 Usefulness**

2.4 Sketching
- **2.5 Objectives**
- **2.6 Techniques**
- **2.7 Objects**
- **2.8 Cartooning**

3.9 Engineering Drawings
- **3.10 Objectives**
- **3.11 Format**
- **3.12 Working Drawings**
- **3.13 Quiz**

4.14 Orthogonal Projection
- **4.15 Objectives**
- **4.16 Theory**
- **4.17 Standard Views**
- **4.18 Auxiliary Views**
- **4.1 Common Practices**
- **4.2 Quiz**

5.0 Pictorials
- **5.1 Objectives**
- **5.2 Oblique View**
- **5.3 Isometric View**
- **5.4 Perspective View**
- **5.5 Quiz**

6.6 Sections
- **6.7 Objectives**
- **6.8 Full Section**
- **6.9 Half Section**
- **6.10 Offset Section**
- **6.11 Broken-Out Section**
- **6.12 Revolved Section**
- **6.13 Removed Section**
- **6.14 Common Practices**
- **6.15 Quiz**

7.0 Dimensioning
- **7.1 Objectives**
- **7.2 Definitions**
- **7.3 Guidelines**
- **7.4 Common Shorthand**

8.5 Tolerancing
- **8.6 Objectives**
- **8.7 Definitions**
- **8.8 Practical Fabrication Techniques**
- **8.9 Fits**
- **8.10 True Position**
- **8.11 Datums**
- **8.12 Surface Features**
- **8.13 MMC**
- **8.14 Quiz**

9.15 Descriptive Geometry
- **9.16 Objectives**
- **9.17 Basic Principles and Relationships**

9.3 Line Visibility

9.4 Distance Between Lines

9.5 Edge Views and True Shapes

9.6 Dihedral Angle

9.7 Intersection of a Line and a Plane

9.8 Intersection of Two Planes

9.9 Intersection of a Plane and a Solid

9.10 Intersection of Two Solids

9.11 Surface Developments

9.12 Contours and Cut-and-Fill

9.13 Shadows

Figure 1 *- Table of Contents.*

tive geometry. It illustrates the two basic principles of orthogonal projection, ten geometric relationships fundamental to descriptive geometry, and illustrates how these are applied to solve typical descriptive geometry problems. Step-by-step examples that illustrate typical descriptive geometry constructions are ubiquitous in this chapter.

All chapters contain example problems that demonstrate how to use the concepts presented within them. These problems are usually given in a step-by-step format and are accompanied by quizzes that allow students assess their understanding of the fundamental concepts contained in the chapter.

Layout and Navigation

The typical layout of a tutorial page is shown in *Figure 2*. The contents of the central region change from page to page, but the border is constant; the menubar is always present, as are the page forward/backward arrows at the lower right-hand corner of the page. Most pages also contain a "repeat" and a "pause" button, located in the lower right-hand corner of the page, that allow the audio narration to be replayed or paused. Whenever an animation appears on the page, a "repeat animation" button is present so users can replay the animation. Control of the user environment is done through the menubar. For example, the "Options" submenu allows the audio narration to be turned on or off and its volume adjusted.

Navigation in *Graphics Interactive* is managed through the menubar and the page forward/backward arrows. The "Navigate" submenu allows users to navigate directly to any chapter or subsection listed in *Figure 1* or to simply move one page ahead or back in

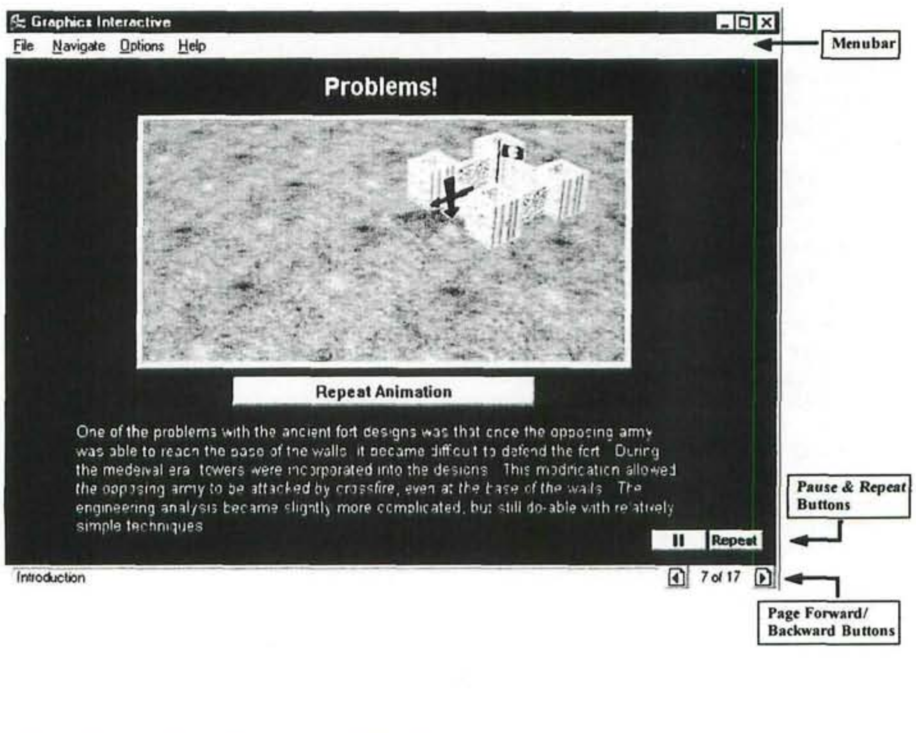


***Figure 2** - Layout of a typical page. This page is taken from the Introduction chapter.*

the current section. The page forward/backward arrows allow users to page through a section of the tutorial, or to go directly to any page within the current section by entering a page number.

Using Multimedia

The novelty of this application is not the material that is presented, but rather the multimedia format in which it is presented. Multimedia in the computer first became widespread in the computer-game industry. The term "multimedia" grew from merely referring to using more than one type of media to, as Oblinger (1992) states, "using a computer to provide a multisensory experience" where a key part of this experience is that it is "controlled and managed by the participant's actions or decisions." The use of a computer gives multimedia several tools that are useful in engineering education.

The most important benefit provided by multimedia is probably that of interaction...

Advantages of Multimedia

The combined use of the different media types may offer advantages presenting topics that are sometimes difficult to understand, visualize, and/or illustrate. For understanding orthogonal projection or how a 2D representation correlates to a 3D object, 3D animation of objects, scanned pictures and sketches, and other media have a significant advantage over the inanimate graphics of traditional text books, as indicated by Wilson (1996).

An additional benefit of multimedia presentation is that more than one type of media can be used to simultaneously present information. Conventional textbooks use only one sense (e.g., sight with a printed page) to present information. Sometimes the intended message may be distorted if only one media type is used, as indicated by Mohler (1996), especially in circumstances where the focus should be on the graphics being presented with the text (Wilson, 1996). In such cases, using both motion and sound through multimedia can alleviate the difficulties with traditional printed media.

A third tool that is specific to multimedia is hypermedia. Hypermedia permits flexible access of media by allowing random information access. A primary means of implementing hypermedia involves highlighting key words in multimedia applications that send the user to additional material related to the key word(s) when activated by a mouse-button click. Hypermedia in this form is called hypertext. Hypertext allows users to easily access information in a random sequence, in contrast to film, video, or audio tape. This feature makes the typical human trend of randomly accessing the pieces of information needed to construct a complete picture of the material formalized and easily implemented, as indicated by Hubbard and Murphy, (1996). The concept can also be extended to other types of media, such as interfaces that allow users to click on designated regions of the screen to access information associated with objects. Overall, hypermedia provides a way of linking information so that learning can be enhanced through juxtaposition.

The most important benefit provided by multimedia is probably that of interaction. Mohler (1996) has done an extensive literature review and cites studies indicating that interacting with information can have a positive effect on learning since people remember/internalize more information if they interact with it (e.g. hear, see, and do). Multimedia provides an excellent means of generating interaction through interfaces that require the user to make choices and perform actions.

Applying Multimedia in an Engineering Graphics Tutorial

Nearly all of the topics encountered in an engineering graphics course deal with 3D objects or concepts, which are often difficult to visualize for students. Orthographic projection and descriptive geometry are topics that are sometimes especially difficult. In both these cases, 3D representations and animation of these representations may be beneficial to students trying to relate 2D drawings to the 3D objects they represent.

It was, therefore, the authors' intent to take advantage of the ability of multimedia to present different media types by including 3D animation with every topic presented in the tutorial. Some representative examples of these animations are shown in Figs. 3 and 4. Figures 3a-d show four frames from an animation that depicts the meaning of a half-section view. The animation begins with an isometric view of the part (*Figure 3a*), shows a cutting plane sectioning the part (*Figure 3b*), animates the removal of the sectioned material (*Figure 3c*), and rotates the sectioned part into profile view (*Figure 3d*). This animation offers students an alternate presentation of what they should visualize when they see a section view on an engineering drawing.

Figure 4 shows three frames of an animation illustrating the concept of the cutting-plane method used in descriptive geometry. This technique may be difficult for students to visualize, but the animation used to derive *Figure 4* demonstrates the principle with possibly more clarity than is possible with textbooks or lectures. The animation begins with an isometric view of the front and horizontal viewing planes and of a line intersecting a triangular plane. Then the imaginary cutting plane used in the cutting-plane

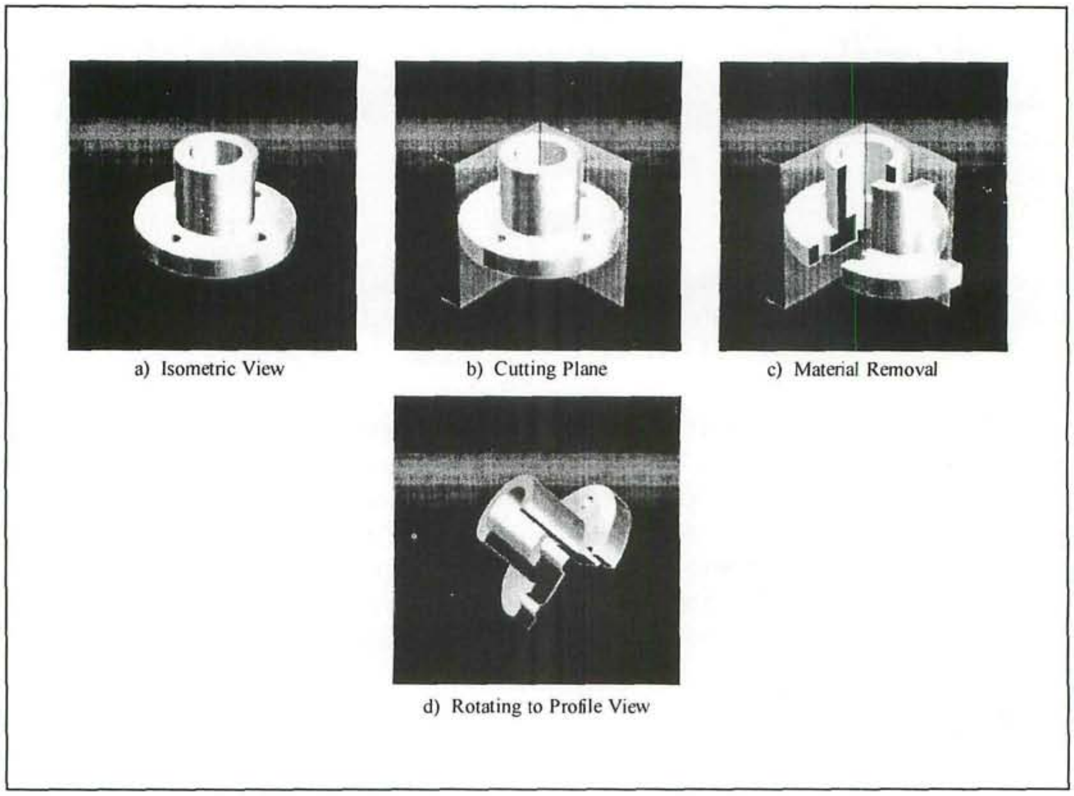
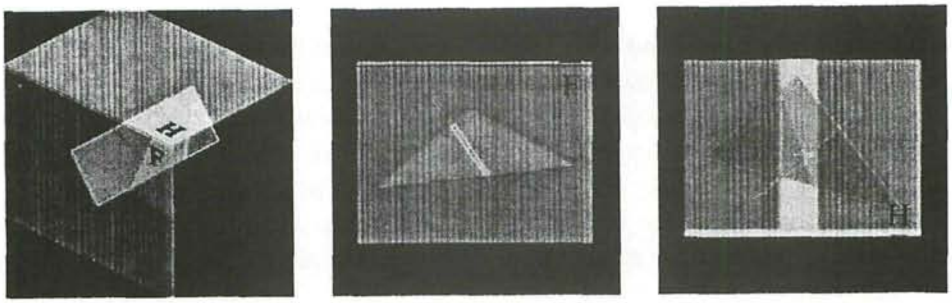


Figure 3 *- Frames from an animation illlustrating a half section.*



a) Cutting Plane Cuts Through Objects   b) Front View   c) Horizontal View

***Figure 4** - Three frames from an animation illustrating the cutting-plane method.*

nary cutting plane used in the cutting-plane moves in (*Figure 4a*), and everything is rotated into front view to show the cutting plane in edge view (*Figure 4b*). The objects are then rotated into horizontal view to illustrate that the cutting plane is no longer in edge view and that its intersection with the original plane is visible as a line (*Figure 4c*). The intersection of the original line and plane are clearly seen to lie in the cutting plane.

One of the unique interactive schemes employed in this tutorial is the step-by-step format used with nearly all the example problems. The typical format of such exam-

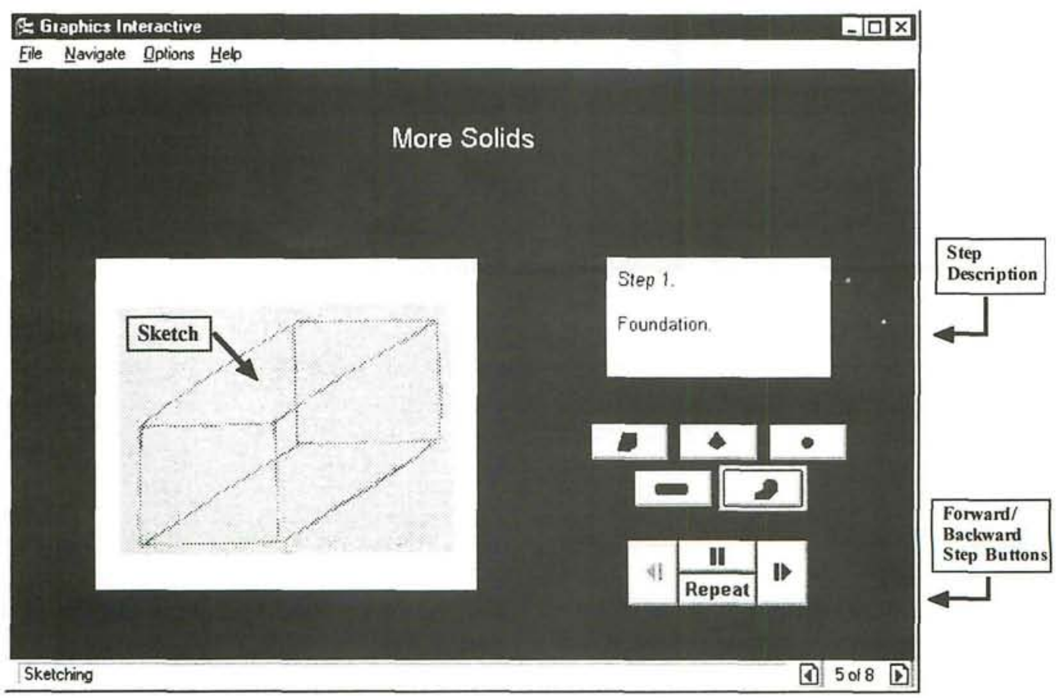


***Figure 5a** - Layout of a step-by-step example in the Sketching chapter.*

page from the Sketching chapter of the tutorial. The forward and backward step buttons are shown in the lower right-hand portion of the page. Clicking on these allows the user to step the solution forward or backward as desired, with no pressure to understand a step quickly before continuing. Each step shows a graphical portion of the step at the left and a textual description of the step above the step buttons. The effect (on the graphic) of clicking the forward step button is shown in *Figure 5b*. The steps are rudimentary so that students can easily observe how the solution develops. *Figures 5 c-f* show the steps to the completion of the sketch of the bracket. *Figure 6* shows two consecutive steps in the solution to a descriptive geometry problem as it is presented in the tutorial. Again, students can click forward and backward through the steps until they fully understand how and why each step is made.

Another useful tool involves placing "hotregions" in interactive interfaces. Hotregions are areas of the screen that users can click to evoke an action from the tutorial related to what is shown in that portion of the screen. An example of such an interface is shown in *Figure 7*, which illustrates a page from the Orthogonal Projection chapter. Here all 6 projection planes are shown in a developed view at the right. At the left is shown an isometric view of the part. By clicking on a view (e.g., the back view) in the picture on the right, the user causes the object in the view at the left to rotate until its orientation mimics the orientation depicted by the 2D view clicked. The user thus makes an association between a 2D orthogonal projection and the corresponding 3D orientation of the part.

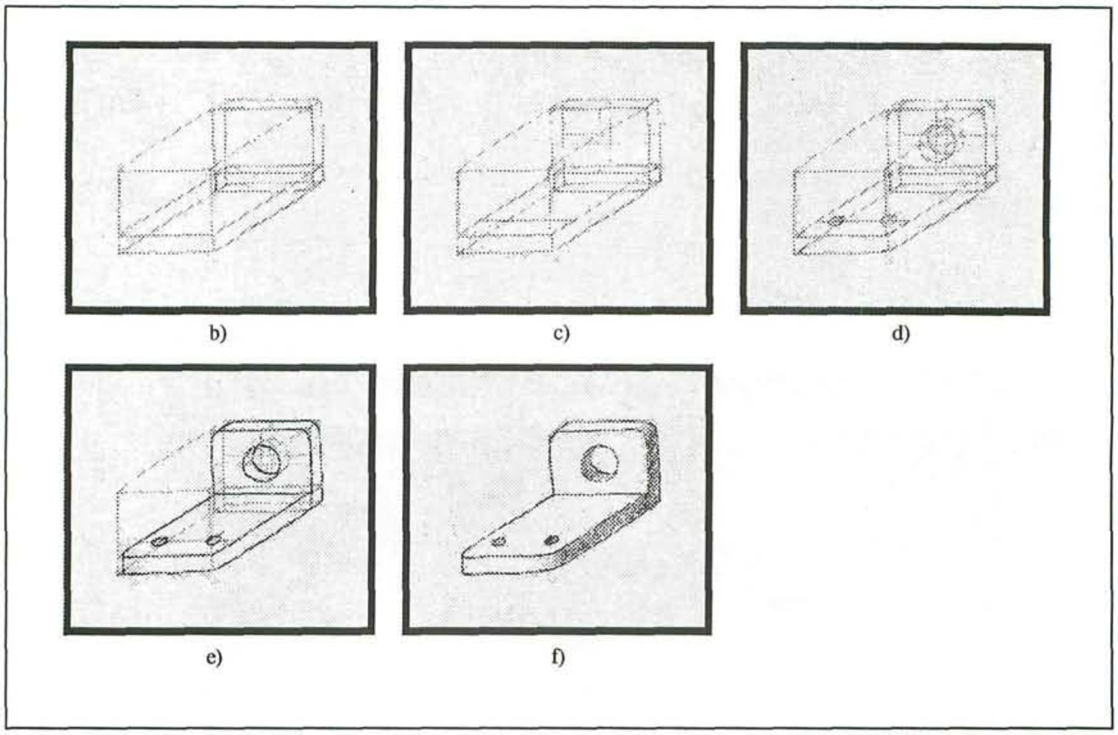
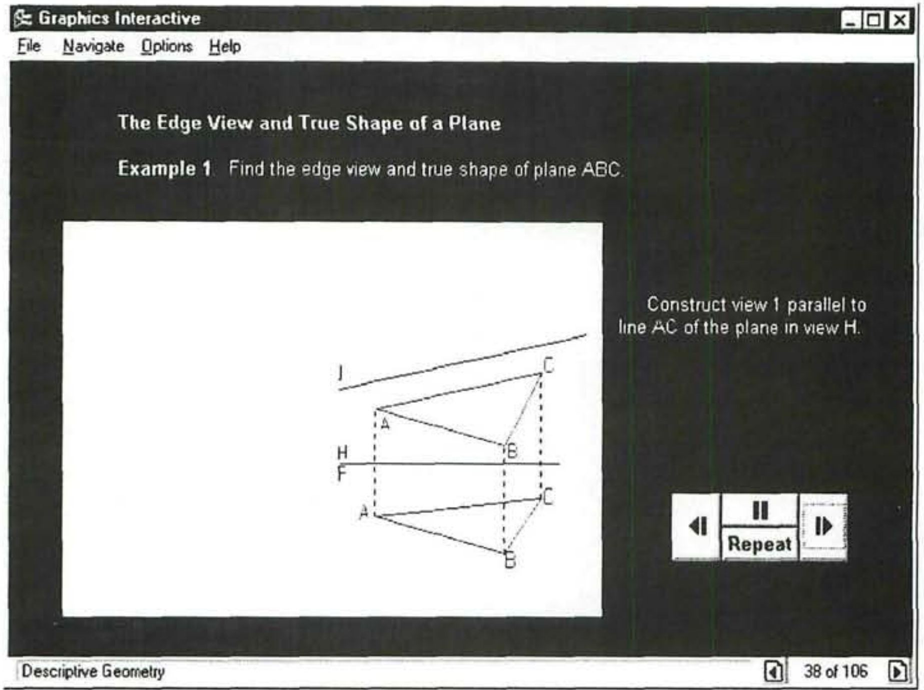
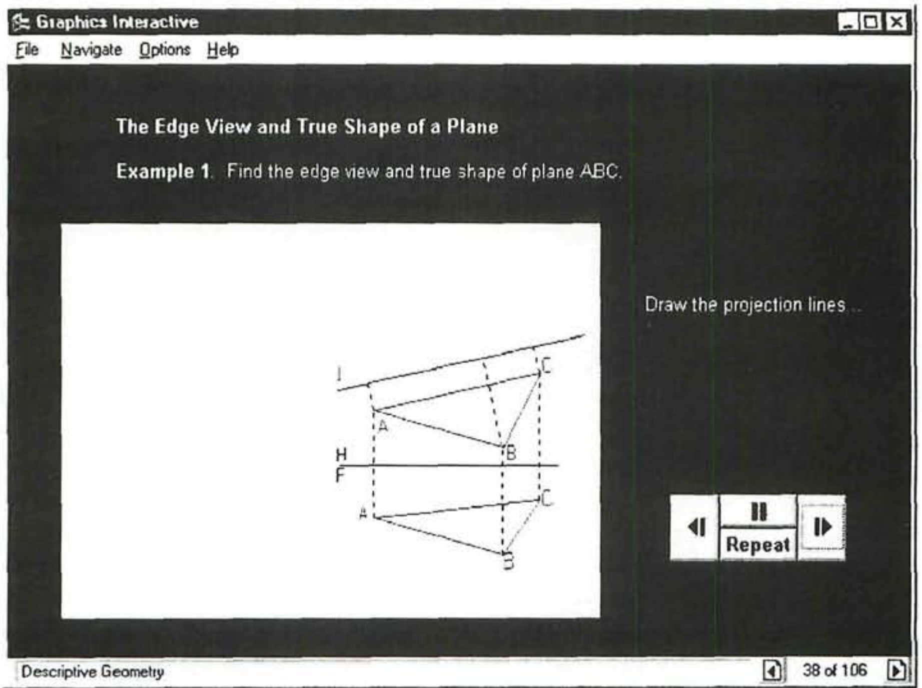


Figure 5b-f *- The steps to completing the sketch of a bracket. The steps are advanced by clicking the forward step button on the page in Figure 5a.*

A more interesting interactive example is depicted in *Figure 8*. This example appears in the Tolerancing chapter and is designed to



a) Solution Step 2



b) Solution Step 3

***Figures 6 a-b** - Two consecutive steps in the solution of a descriptive geometry problem. Toggling between the two steps is allowed by the forward/backward step buttons.*

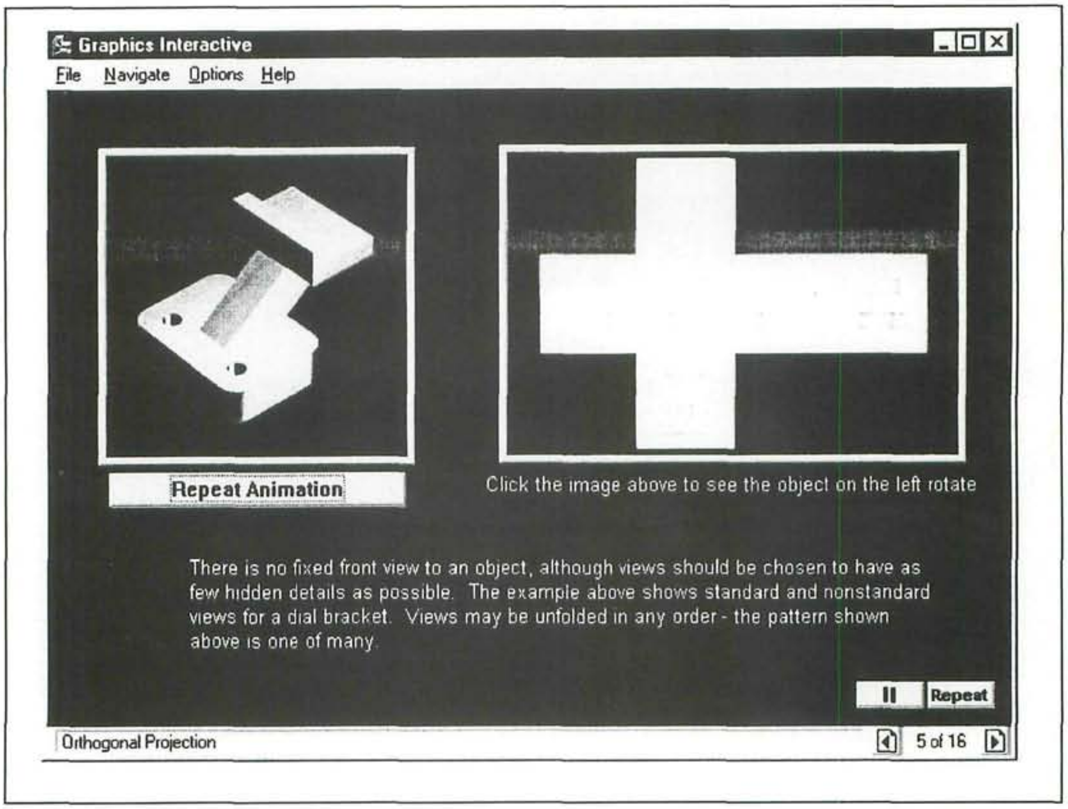


Figure 7 *- Intercative example containing "Hotregions." Clicking on a view on the right causes the 3D image on the left to rotate to show the corresponding side of the part.*

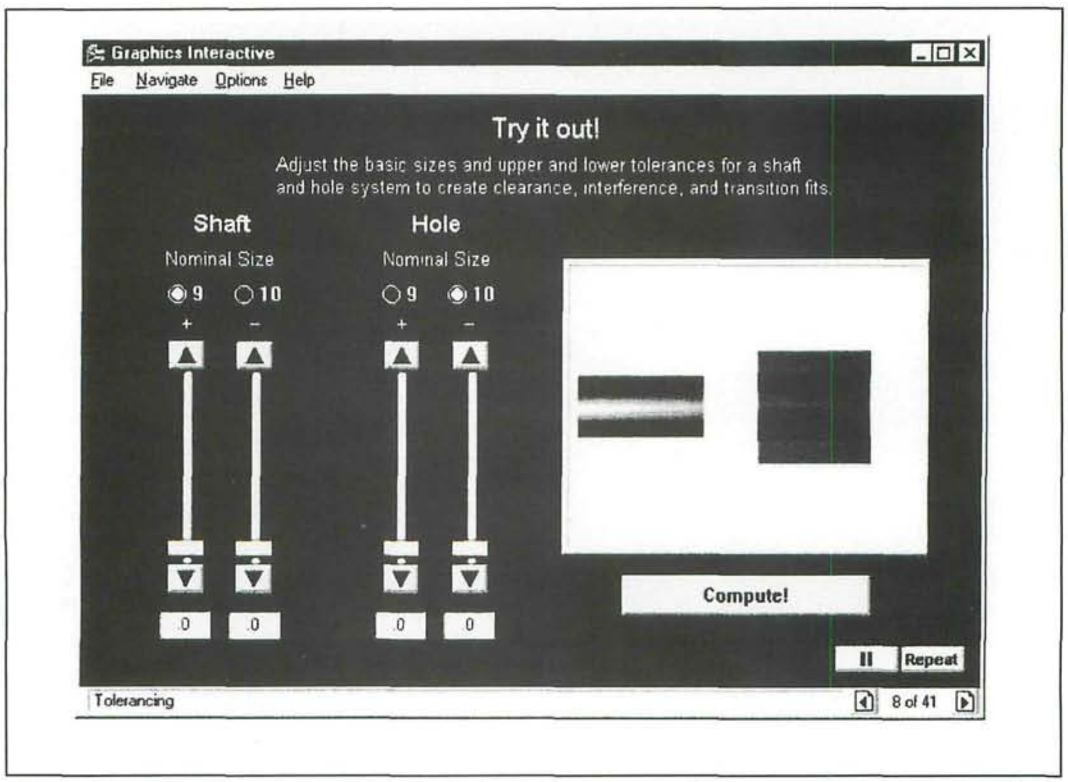


Figure 8 *- An interactive example in the Tolerancing chapter. Users can adjust the sizes and tolerances of the parts to learn about different types of fite.*

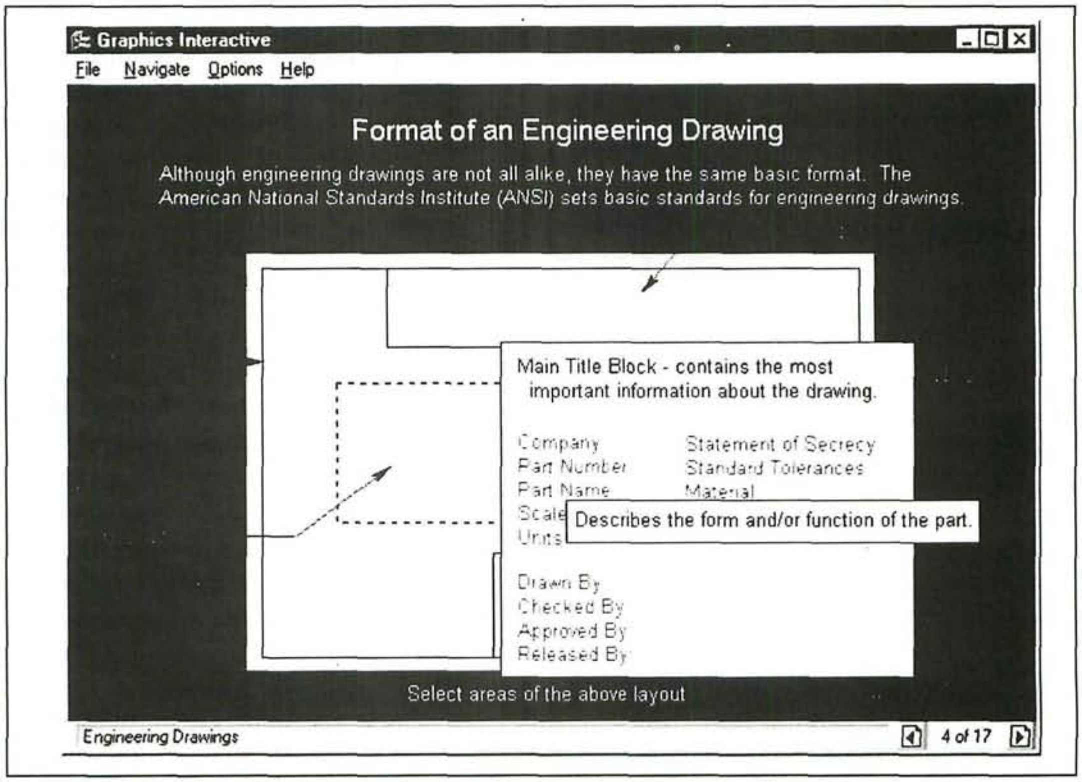


Figure 9 *- Example of a page that uses Hypertext. Clicking on a word or phrase accesses information about the item.*

let the user explore the concept of fits. Students can adjust the nominal sizes of the pin and hole as well as the upper and lower tolerances of these sizes. By pressing the "Compute!" button they will know whether or not the fit is clearance, interference, or transition. An animation is also provided to illustrate the meaning of these terms, e.g., for an interference fit, a hammer appears to help pound the pin through the hole.

Hypertext and information links also permeate *Graphics Interactive*. Hypertext is used to branch a specific topic into sub-topics. Hypertext appears green, so users will know when additional information is available. The example shown in *Figure 9* illustrates the terminology and layout of a standard engineering drawing. By selecting a designated area, the user can bring up a box describing the items that should be located in that area of the drawing. If any of these items is unfamiliar to the user, he or she can select the item to bring up a definition of the term. This method of branching to new information offers the user easy access to the information.

An area where information links are particularly convenient is in the quizzes found in each chapter. Quiz questions (whose possible responses are true, false, or inconclusive) allow students to test their knowledge of the material just covered. The response for a correct answer to a question is shown in *Figure 10a*. For an incorrect answer, however, the tutorial's response is shown in *Fig.ure 10b*. This window gives the student an opportunity to try again or to review the lesson where the necessary information is discussed before trying again. If the student chooses "review lesson" he or she is sent to the appropriate page, and a "back" button appears in that page so that the student can return to the quiz when he or she is finished reviewing. Thus the quizzes are linked with

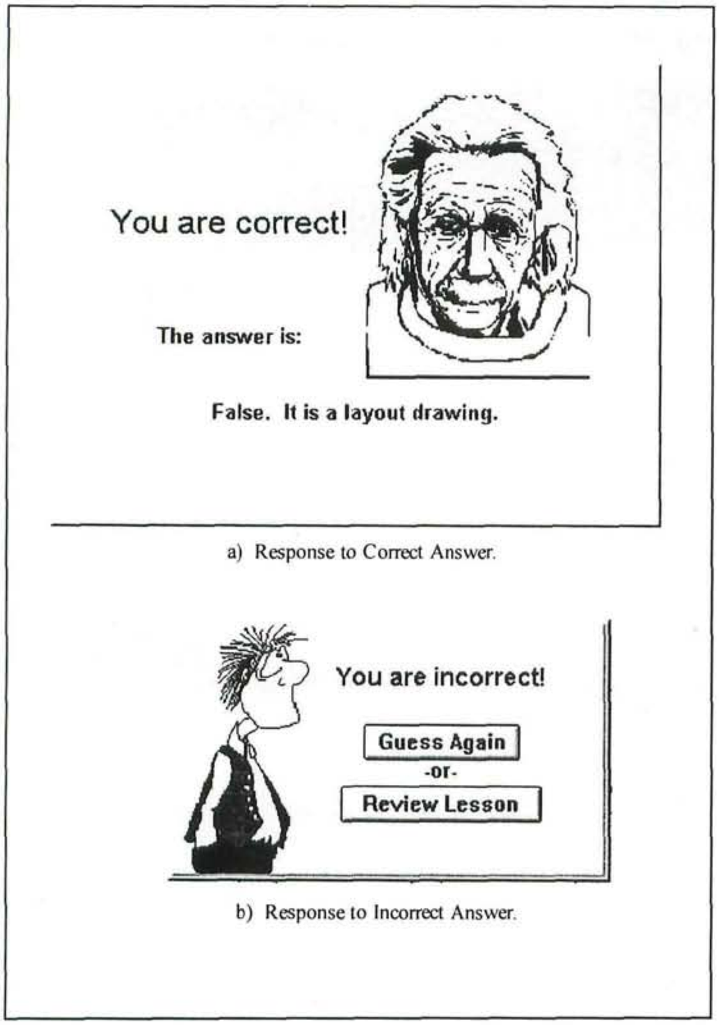


***Figure 10** - Responses to correct (a) and incorrect (b) student answers. For an incorrect response, the student can guess again or review the material.*

the body of the tutorial, which should facilitate the review and assimilation of important topics.

All of the text found in the tutorial is narrated and available to users that have audio cards in their computers. Narration of the text presents three advantages. First, as suggested by Mohler (1996), it appeals to the multi-sensory way that people think and live. Second, reading text from a computer screen can be traumatic to the eyes, so relieving the necessity of reading all the text can be advantageous. Finally, it allows students to focus their attention on the graphics, which is the most important aspect of the tutorial. Most of the important information is contained in the graphics. If students are forced to constantly alternate between reading textual descriptions and viewing graphics, they may lose all or part of the point of the tutorial. Thus, audio narration was included to allow students to view the graphics and simultaneously hear descriptions of the graphics, resulting in a multi-sensory learning experience. An audio volume control is provided through the menu items, and students can turn off the audio narration as desired.

Tutorial Evaluation

The concept of using multimedia in engineering graphics instruction at U.C. Berkeley was pioneered with a multimedia descriptive geometry (DG) tutorial available to students in the engineering graphics laboratory. This tutorial was used extensively in the engineering graphics course at U.C. Berkeley for 3 three years, and evaluations of its effectiveness were performed by surveying the students in 1993 and 1995. The core of this pilot tutorial appears in the Descriptive Geometry chapter of *Graphics Interactive*. A positive evaluation of the multimedia descriptive geometry tutorial's effectiveness served as impetus for the development of *Graphics Interactive*. A survey evaluation of the beta version of *Graphics Interactive* was performed in 1996.

All three surveys included questions about the usefulness of the respective tutorials in relation to the course. Some of the key questions that the students were asked, on a scale of 1 (not helpful) to 5 (very helpful), were the following:

a. How useful was the tutorial in explaining lecture material? 1 2 3 4 5

b. How useful was the tutorial in helping you do the homework? 1 2 3 4 5

c. How useful were the tutorials in preparing you for the exams? 1 2 3 4 5

d. Rate the overall usefulness of the tutorial: 1 2 3 4 5

In general, responses to these questions were very positive. The mean and standard deviation (s) of student responses are shown in *Table 1*. This table also gives the 1993 and 1995 data evaluating the helpfulness of the quizzes within the descriptive geometry tutorial [question (e)]. For the 1993 survey, 108 students were surveyed while 104 were surveyed in 1995 and 63 in 1996.

As indicated by the 1993 and 1995 data in *Table 1*, the students found the descriptive geometry tutorial quite helpful. Based on their comments in these surveys (which also relate to the Descriptive Geometry chapter of *Graphics Interactive*), most students felt that it was an excellent supplement to lectures, giving them a chance to slowly review in detail what is covered in class. A significant number of students also commented that the DG tutorial helped them visualize the solutions and techniques used. Several students liked the DG tutorial so much that they suggested making it available to the students at home (which was an additional impetus for creating *Graphics Interactive*). These sentiments are summarized by one student who comments that the DG tutorial "explain[s] problems completely, and you can go at your own pace."

Compared to the 1993 version, the 1995 version of the tutorial contained more advanced example problems and increased use of hypertext linking to "connect" related topics. The added example problems in the 1995 version may have influenced the substantial increase in the mean response for question (b) indicated in the 1995 column of *Table 1*. The 1995 survey also included questions about the hypertext links. In response to the question "Were the hypertext links helpful in locating information that supplemented the examples?" the mean response (again on a scale of 1-5) was 4.19, with s = 0.82. Clearly this added feature was viewed positively by students, and as a result, *Graphics Interactive* was designed with extensive hypertext linking.

In outlining the results to the forerunner of *Graphics Interactive*, it becomes evident that the reason the project was expanded to cover more material and made available on CD-ROM was because students found it to be a useful learning tool. The DG tutorial showed that students responded well to self-paced, step-by-step examples that illustrate and reiterate the topics covered in lecture.

Question	Statistic	Year		
		1993	1995	1996
a	mean	4.18	4.26	4.23
	σ	0.77	0.75	0.85
b	mean	3.72	4.16	4.15
	σ	0.98	0.86	0.84
c	mean	3.59	3.83	3.64
	σ	1.02	0.9	0.91
d	mean	4.02	4.17	4.09
	σ	0.85	0.73	0.74
e	mean	4.08	4.11	
	σ	1.13	0.83	

***Table 1** - Summary results of 1993 and 1995 survey's evaluating the descriptive geometry tutorial and the 1996 survey evaluating the beta version of **Graphics Interactive**.*

Graphics Interactive expands on these ideas with enhanced graphics, 3D animations, and extensive hypermedia linking. The students' reactions are indicated by the survey results shown in Table 1, which show no significant difference in the approval ratings of the 1995 version of the descriptive geometry tutorial and *Graphics Interactive*. Evidently, the new tutorial is seen as an effective tool by the students. Student comments about *Graphics Interactive* also indicate that the multimedia features were helpful, and 86% of the students that responded requested more example problems.

These survey results demonstrate the success the authors have had assisting students with multimedia tutorials. Nevertheless, a controlled comparison of classroom instruction with computer based instruction (i.e., multimedia) for an engineering class (Hummer *et. al.*, 1996) suggests a more qualified interpretation of such results. In their report, Hummer et. al. (1996) compare students performances in a traffic engineering course when they are taught using traditional classroom techniques and when they are taught using multimedia applications containing animation, hypertext, and quizzes. The results of the investigation showed no significant difference between the two groups of students. Surveys given to these students, however, indicate students felt that computerized instruction could be a supplement to classroom instruction. Hummer et. al. also note that their results are for only one type of engineering class, and results may differ for other classes. The authors strongly feel that engineering graphics is one topic where multimedia instruction can give its users a significant advantage (in terms of visualization and understanding) over other students.

Multimedia is an exciting tool that is just beginning to realize its potential in engineering education.

Concluding Remarks

Multimedia is an exciting tool that is just beginning to realize its potential in engineering education. It provides many spectacular tools that can enhance traditional means of instruction. Some of the most dramatic are animation, audio (music, text narration, etc.), and nonlinear navigation with hypermedia. The results of surveys and investigations suggest several key recommendations for multimedia in engineering education:

a) Multimedia can be an effective supplement to traditional engineering instruction (Hummer et. al., 1996) (Wilson, 1996), but at present, it should not replace traditional methods.

b) The tools provided by multimedia should be used to their fullest extent in an effort to provide interactive interfaces, promote a self-paced learning environment, and enhance visualization with animation/graphics.

c) Multimedia instruction applications should be made widely available to students. At U.C. Berkeley this is done by making *Graphics Interactive* available on CD-ROM so students can use it on their own computers or on the computers provided by the University in the engineering graphics laboratory.

d) Systematic controlled experiments should be done to better determine the overall effectiveness of multimedia instruction in engineering education, the specific areas where it is most helpful, and what tools provided by multimedia are most useful in engineering instruction.

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