Development of an Interactive CDROM-based Tutorial for Teaching MATLAB

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Abstract— **This paper describes the development of an interactive computer-based tutorial for MATLAB. This tutorial has been developed for undergraduate or graduate students who have had little or no exposure to MATLAB. Students are guided through new concepts and syntax with useful aids such as audio, video and interactive exercises. The exercises, implemented in a specially designed exercise window, give the students an opportunity to use MATLAB to solve problems immediately after covering new concepts. The exercise window has a background interface to MATLAB and thus all commands entered in the window are executed by MATLAB. Hints, example solutions, multiple choice quizzes and test problems, requiring the use of proper MATLAB structure and syntax, add to the learning experience.**

This project was initially undertaken to investigate student response to alternate computer-based teaching methods. Thus student input has played an important part in the development of this tutorial. Subjective feedback from students, which is presented in the paper, indicate great promise for this alternate approach to teaching MATLAB.

The reader can obtain more information on the tutorial at the web site www.m-tutor.usask.ca. The tutorial has been published by Prentice-Hall Canada (ISBN 0-13-083396-7).

Keywords— **MATLAB, Computer-based instruction, CBI, Courseware, Computer-assisted learning**

I. Introduction

MATLAB is a computer programming environment, which is used to perform and visualize numerical computations. MATLAB's ease of use relative to traditional programming languages has made it very popular in academic and industrial environments. For example, an indication of the popularity of MATLAB is evident from the large number of textbooks that make use of MATLAB. A current list of these textbooks is available from the MathWorks web site [1]. Thus, given that MATLAB is an important tool for students in their academic and professional careers, it should be formally taught in the undergraduate curriculum. This is not generally the case, since MATLAB is a relatively new tool and there are few resources available to add new items to the undergraduate curriculum. These students use MATLAB, but few have a good understanding of the basics of this non-conventional, matrix-based programming language.

In an effort to improve the students understanding of this programming language, a project was started in early 1996 to investigate alternate approaches to teaching MATLAB. This resulted in an interactive computer-based tutorial, named M-Tutor, that students could use to independently learn MATLAB. Presently, there are no computer-based interactive tutorials available for learning MATLAB, but there are a number of internet based tutorials [2], [3], [4]. All of these tutorials are basically computer-based textbooks, which lack any significant student interaction or feedback.

The major goals of this tutorial were to:

1. engage students as active learners in exploring new concepts immediately with interactive exercises;
2. allow students to proceed at their own pace;
3. permit the learning to take place off-campus; and
4. make more effective use of faculty teaching time and student study time.

The result is an effective tool that can be used to independently study MATLAB. It is an introductory tutorial and thus could be used in any appropriate first or second year undergraduate math class, such as linear algebra. It could also be used to supplement any higher year classes, but only to introduce the basics of MATLAB.

This computer-based MATLAB tutorial is an example of interactive computer-based instruction (CBI). CBI is an active area, which is evident from the increasing number of published papers. For example, the August 1996 IEEE Education Transactions was dedicated to a special issue on the application of information technologies to engineering and science education. Within this issue there were a number of papers directly related to computer-based instruction [5], [6], [7], [8], [9]. There are also a number of useful books in this area, which provide information on theoretical aspects of CBI design [10], [11] to the more practical implementation details [12].

An important part of designing computer-based instruction is the learner interface to the material. This is an active research area, especially learner control research. "Learner control is defined as those design features of CBI that enable learners to choose freely the path, rate, content, and nature of feedback in instruction" [13]. The contrasting approach to learner control is program control. Program control is defined as the "design features that determine the path, rate, content, and feedback in instruction for learners" [13]. The general approach used in the implementation of this tutorial, perhaps best fit under the label of program control. The author has kept majority control over the path, content and nature of feedback and the learner has some control over the path with complete control over the rate. Program control was chosen, since this is the first project of this type and the safest approach was to extend the lecture/assignment based method. This approach includes a heavy emphasis on drill exercises with

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feedback; to reinforce the material presented.

The remainder of this paper is divided into three major sections. The first section is the Design Process, which describes the approach used in developing the computer-based tutorial. The next section is Implementation, which presents the implementation details, including a description of the direct interface to MATLAB that is used for exercise evaluation. The last major section is Student Evaluation Results, which presents some subjective undergraduate student evaluation results.

II. Design Process

The design process used in developing this computer-based tutorial is similar to the Conceptual Model for Designing Instructional Hypermedia presented in [14]. This model is divided into seven components:

1. Learner Characteristics
2. Goals/Objectives
3. Pedagogical Model
4. Navigation
5. Structure
6. Format
7. Content

The design process consists of identifying and specifying each of these components.

Learner Characteristics defines the target market for the computer-based application. This includes descriptions of previous knowledge, learning styles and motivation of the target market. The assumed Learner Characteristics for the MATLAB tutorial market are:

1. The intended users of this tutorial are undergraduate students who have had little or no exposure to MATLAB.
2. A basic math/computer background is assumed. A first course in linear algebra, probability theory and calculus would be an asset, though not a requirement for this tutorial.
3. The learning styles of these students are not well defined, but they are familiar with the traditional lecture/assignment approach, which integrates auditory and visual presentations and reinforcement of topics through student interaction using questions and assignments. A conscious attempt has been made to cater to the different learning styles, which include 'reading, listening and doing'.
4. In a university environment the curriculums are heavy and the students tend to focus their limited resources on the higher value items within the grading system. Thus it is assumed that this tutorial will be integrated into an existing undergraduate class and the students will be rewarded appropriately for successfully completing the tutorial.

The major Goal/Objective of this computer-based application is to provide an effective tool for the independent study of MATLAB, producing a confident student able to use MATLAB for numerical computation and displaying graphics.

The Pedagogical Model defines the method used to teach the content. The approach chosen here, is a tutorial with reinforcement using exercises and quizzes. This method was selected since the material taught consists of MATLAB commands and concepts, which lends itself to a sequential and logical presentation. Students are also familiar with this method since it is similar to the traditional lecture/assignment approach. The exercises use a form of elaborative feedback [15] involving hints and the correct answer. Audio, in the form of voice, is also used throughout the tutorial. A number of experimental audio methods are used and evaluated through student feedback.

Navigation refers to the user interface design, which defines how the student can move through the computer-based application. This is definitely the most important non-content design issue. The guiding principles used in designing the navigator were:

1. The overhead in learning how to use the navigator should be low. A navigation format similar to other Windows-based applications was chosen to minimize this overhead.
2. The students should feel that they have full control over the tutorial at all times. Details of the techniques used are presented in the Implementation section.

The Structure is defined as the overall organization of the content. Given the pedagogical model and the nature of the content, a hierarchical structure was chosen for the tutorial. The content is organized in sections and subsections, which are defined by common material.

The Format is defined as the type of media that is used to deliver the content. The media used in this tutorial consists of text, audio, video and graphics. Elaborate graphics and animation are not used, because of the nature of the content, which consists of descriptions of basic MATLAB commands and concepts.

The Content is the information presented in the computer-based application. Since the intended users have a general math background with possibly little exposure to matrices, it was decided to present the basic math related content as follows:

1. The students are first introduced to MATLAB operators and functions using scalar variables.
2. Vectors are then defined and an expanded list of MATLAB operators and functions are covered, including plotting, relational and logical math.
3. Finally, matrices and their associated operators and functions are introduced, including solving sets of linear equations.

Since the students are familiar with scalar operations, the scalar math section introduces the student to MATLAB without the complication of matrix notation. Many of these scalar operators and functions can also be applied to vectors and matrices, which makes the transition to vector and matrix math easier.

III. Implementation

This section describes the tutorial implementation. The section is divided into the following subsections: Authoring

Package, Content, User Interface, Audio, Exercise Interface and Section Evaluation.

A. Authoring Package

There are a variety of tools available for software implementation of computer-based applications. These range from using traditional programming languages such as C++ to icon-based multimedia authoring tools. Since resources were limited in this project a decision was made to use an authoring package to avoid spending substantial amounts of time on programming. The authoring package was selected in the summer of 1995. At that time the two major packages that were evaluated were Authorware, which is now supplied by Macromedia [16] and Iconauthor, which was available from Asymetrix [17] and has now been replaced with Toolbook II Instructor. Iconauthor was chosen for this project since it was the only product, at that time, which featured cross-platform support for the Windows, Macintosh and Unix operating systems. A description and listing of a large number of authoring tools is available in [18] and at Jamie Siglar's web site [19].

Iconauthor uses graphical icons to build the structure of the application. Content is added to these icons using dialog boxes that define how each icon performs at run time. This icon-based structure makes Iconauthor a relatively easy to use tool to develop interactive multimedia applications that integrate graphics, text, audio and video. Even though most of the programming details are hidden from the user, Iconauthor still has the versatility to handle application specific implementations using features such as Dynamic Data Exchange (DDE) and Dynamic Linked Libraries (DLL).

The relatively easy to use icon-based structure allows the developer to quickly start developing multimedia applications, but these icon-based development tools are still programming languages and it is necessary to use good programming and documentation practices. It is easy for 'icon programs' to become unwieldy when working on large projects.

B. Content

The content is organized in a hierarchical structure that consists of sections, subsections and finally the pages that contain the actual content. Each of these pages presents the student with a new concept or set of commands.

This tutorial is intended for students who have had little or no exposure to MATLAB, thus it begins with the basic structure of MATLAB. The tutorial then focuses on the strengths of MATLAB, basic numerical computation and graphic visualization. Relational and logical math and MATLAB m-file scripts are also introduced. The tutorial is divided into the following major sections:

1. Getting Started
2. MATLAB Variables
3. Scalar Math
4. Vector Math
5. Vectors and Basic Plotting
6. Relational and Logical Math
7. Writing Basic MATLAB Programs
8. Matrix Math

Each of these sections is divided into a number of subsections that focus on a common topic. A listing of the Table of Contents, which includes all section titles and the titles of the pages, can be viewed at http://www.m-tutor.usask.ca/about/contents.html.

The amount of information presented on a page has intentionally been kept small. This allows the student to easily digest the material and the exercises can focus directly on that material. An example of one of the tutorial pages is shown in Figure 1. The bold, underlined words in this figure are hotwords, which can be opened to view additional information or examples. The majority of the pages have a number of interactive exercises that are accessed by selecting the Exercise hotwords at the bottom of the page. These exercises explore the concepts or commands presented on that page. The format of the exercises is described in the Exercise Interface subsection.

C. User Interface

A comprehensive navigator has been developed for the MATLAB tutorial. Some of the features of this navigator are:

1. On page buttons to easily navigate through the tutorial. These buttons can be seen in the top, left-hand corner of Figure 1. From left to right these buttons are: Go back one page, Go to the main menu, Go ahead one page, Access a list of visited pages, Access the bookmarks list, Jump to the last visited page and Jump to the section contents page.
2. Information, Options and Results menu items that access useful information about the tutorial, change tutorial options and present exercise and quiz evaluation results, respectively. These menus are located at the top, left-hand corner of Figure 1.
3. A help window that describes how to use the navigator. This help facility is accessible from the Information menu.

The navigator is also responsible for maintaining the present status of the tutorial. When the tutorial is started the students must enter their name; this is used to generate a database file that keeps track of the students progress. This database keeps an audit trail of the pages the student has visited, the exercises done and the number of attempts made. It is also used to color-code completed material within the tutorial so the student can easily determine which material has been covered. A record is also kept of the last page visited when the user quits the tutorial. When the same user starts the tutorial again, the navigator gives the user the option of going to the main menu or continuing from the last visited page. An advantage of the database is that it can also be used for evaluation purposes. For example, it could be automatically submitted to an instructor through an internet connection.

There are two ways to view the page titles and access those pages in the tutorial. These are the Main Menu and the TOC (Table of Contents). The Main Menu is accessed

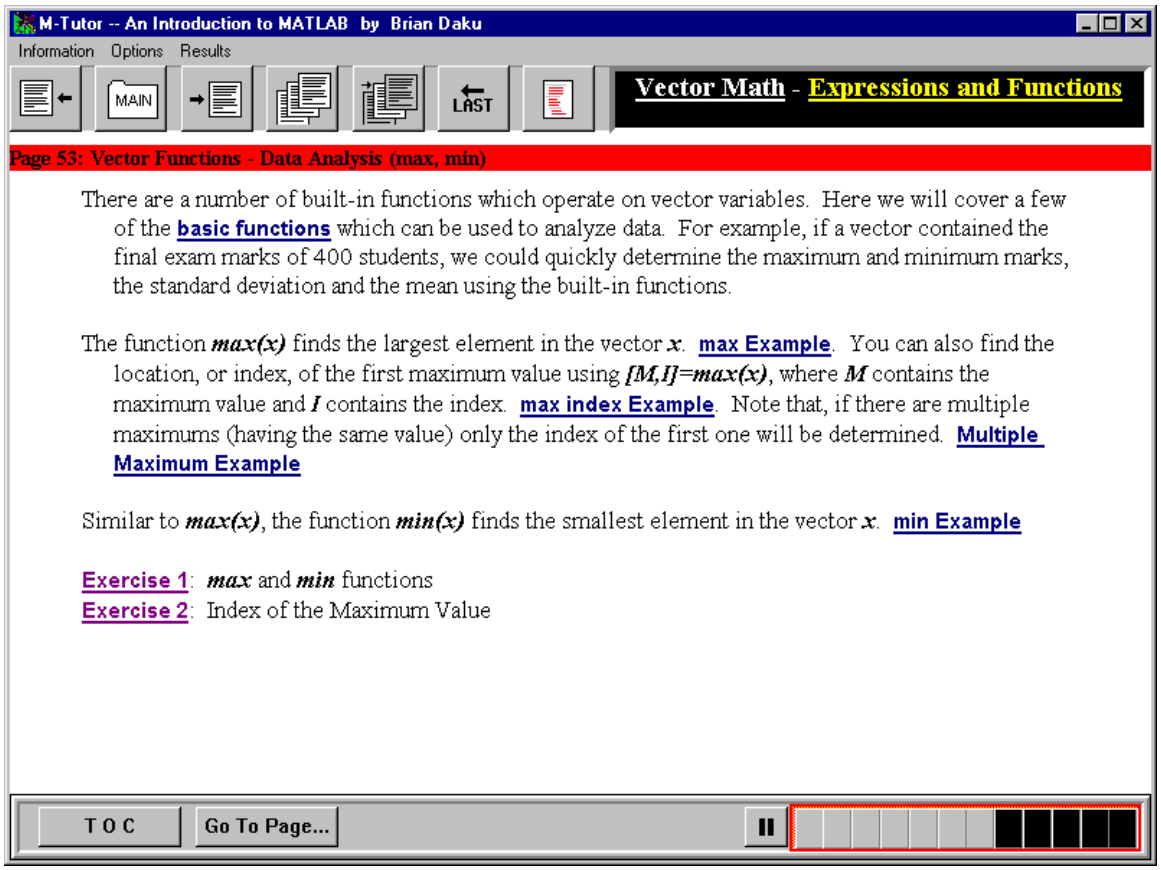

Fig. 1. Example page from the MATLAB Tutorial.

using the on-page navigation button, shown at the top of Figure 1. The Main Menu, when accessed, displays a number of color-coded hotwords. Aqua hotwords display a section submenu when selected. Yellow hotwords display a page, when selected, and these hotwords turn fuchsia after the page has been accessed indicating the page has been completed. The Main Menu, basically, consists of a hierarchical set of these color-coded submenus, which represent the sections and subsections in the tutorial. This approach reduces the amount of information that is presented to the student, which is beneficial for first time users of the tutorial.

The Main Menu approach can become tedious once the user becomes familiar with the organization of the tutorial; thus an alternate method to access the pages is also available. This method was originally accessed, in an early version of the tutorial, through the Information menu. Now it can also be directly accessed by selecting the TOC button located at the bottom left-hand corner of Figure 1. TOC refers to Table of Contents, and selecting this button displays a window, which lists all of the sections, subsections and pages in the tutorial. The scroll bar can be used to move through the list. Selecting any of the hotwords in this window will take the student to that page in the tutorial. There is also one other method for accessing pages, which would typically be used by a student very familiar with the tutorial. This method is accessed by selecting the Go to Page button in the lower left-hand corner of Figure 1. This opens a box, which requests the number of the page the user wants to access.

D. Audio

Audio, in the form of speech, is used throughout the tutorial to enhance the learning process. The audio used in the tutorial can be classified into two types:

1. Audio that repeats the text on the page, referred to here as verbatim-text audio.
2. Audio that provides further explanations of hotword box contents, referred to here as hotword audio.

Verbatim-text audio is used on all of the pages, such as the one in Figure 1. Hotword audio is used in situations where there is very little text. Usually the hotword boxes contain examples and results, which need more explanation.

The students have full control over the audio using a number of on-screen controls and user selectable options. Many of these options and features have been added as a result of the student evaluations. The on-screen controls consist of a pause/play button and a selectable status indicator. The pause/play button can be seen at the bottom of Figure 1 as the button with two vertical lines. If the student left-clicks on this button the audio will pause and the button will display an arrowhead. If the student left-clicks on the button again the audio will start playing. On the right side of the button is an audio status indicator, which

consists of a number of blue blocks each approximately representing a sentence on the page. The black blocks are inactive for that page. As the audio plays each blue block turns red after the completion of the sentence corresponding to that block. At any time the user can left-click on any of the blocks and the audio will start playing at that position in the text.

The user selectable options can be viewed by selecting Audio in the Options menu. A dialog box will appear, which gives the user the option of selecting the following features:

1. Turn the audio on or off, independently, for pages, hotwords and exercises.
2. Select the type of audio delivery, either Stop at Hotwords or Continuous.
3. Select the speed of the audio presentation as slow, normal or fast.

The audio delivery feature Stop at Hotwords, plays the audio until a hotword is encountered, the audio stops and the hotword turns pink. After the student has selected the hotword and closed the hotword box, the audio restarts and continues until the next hotword. Inserting longer or shorter pauses in between each sentence controls the speed of the audio presentation; with fast being no pauses.

E. Exercise Interface

In the Getting Started section of the tutorial the student uses the MATLAB command window to perform some simple exercises. This exposes the student to the actual MATLAB interface. In all of the subsequent sections the student uses a specially designed exercise window to perform the exercises, an example of which is shown in Figure 2.

The exercise problem to be solved is displayed in the top left-hand subwindow. The user can select the Hints button, which displays a list of hints that aid the student in solving the problem. The student solution to the problem is entered in the center subwindow, which is labeled, Enter MATLAB Commands Here. This window has close to the full functionality of the MATLAB command window, including previous command access using the arrow keys. The student enters a MATLAB command and hits the return key and the result is displayed in the MATLAB Response subwindow. This response is the exact response you would see if the command were executed in the actual MATLAB Command window. This is implemented by evaluating the commands using the MATLAB engine through a DLL (Dynamic Linked Library) interface. Once the solution has been entered, the student selects the Evaluate button and a correct or incorrect indication is displayed. The evaluation method uses the MATLAB engine to compare the workspace contents and object variables of a correct solution with the student solution. The student can access an example of a correct solution from the Hints menu after using the Evaluate button.

The main advantage of the exercise window is the direct interface to MATLAB, which allows the student to use MATLAB within the tutorial. The exercise window is also used to guide the student through the problems using hints. The student is informed if their solution is correct or not and then the student is given access to the actual solution to the problem. Another advantage of the exercise window is that a record can be kept of the student's progress through the exercises, this can be used to route the student through remedial exercises if necessary, though this has not been implemented in the current version of the tutorial. Though a basic record of student progress is kept and is accessible through the Results menu. The tabulated results include the number of exercises completed and a percentage mark for each section. This provides some motivation for the student to seriously attempt the questions.

F. Section Evaluation

The student is evaluated at the end of each section of the tutorial. This is done using two forms of quizzes: a Summary Quiz and an Exercise Quiz. The Summary Quiz consists of a number of short questions one for each page covered; the majority of which are multiple choice. These questions review the information presented in the subsection.

The Exercise Quiz consists of exercises that use the exercise window. There is one exercise for each page covered in the subsection. The exercises here do not use the hint feature, but they still provide the answer.

The Results menu is also used to display the tabulated results of the Summary Quiz and the Exercise Quiz.

IV. Student Evaluation Results

Student feedback has played an important part in the development of the MATLAB tutorial. This section presents some of the results from two major student evaluations:

1. In March 1997, sixty second year Electrical Engineering students evaluated the tutorial.
2. In March 1998, thrity-nine second year Electrical Engineering students evaluated the tutorial.

The evaluations were done on-campus in a computer lab. The students spent between three and five hours to complete a portion of the tutorial (55 pages).

The students then completed a survey form that consisted of 29 multiple-choice questions, which were divided into three sections: Background, Overall Impressions and Detailed Impressions. The results of some of the survey questions are presented below under these three section headings. These survey questions were very subjective and they were used to obtain feedback to improve the tutorial. Thus they do not provide objective measures of the effectiveness of computer-based tutorials. The complete survey results can be accessed at the web site, http://www.m-tutor.usask.ca/about/1997.html and www.m-tutor.usask.ca/about/1998.html.

A. Background

These second year students had very little exposure to MATLAB, prior to using this tutorial, which is indicated by the results of the question shown in Figure 3. As previously stated, this is a defining feature of the target market for this tutorial.

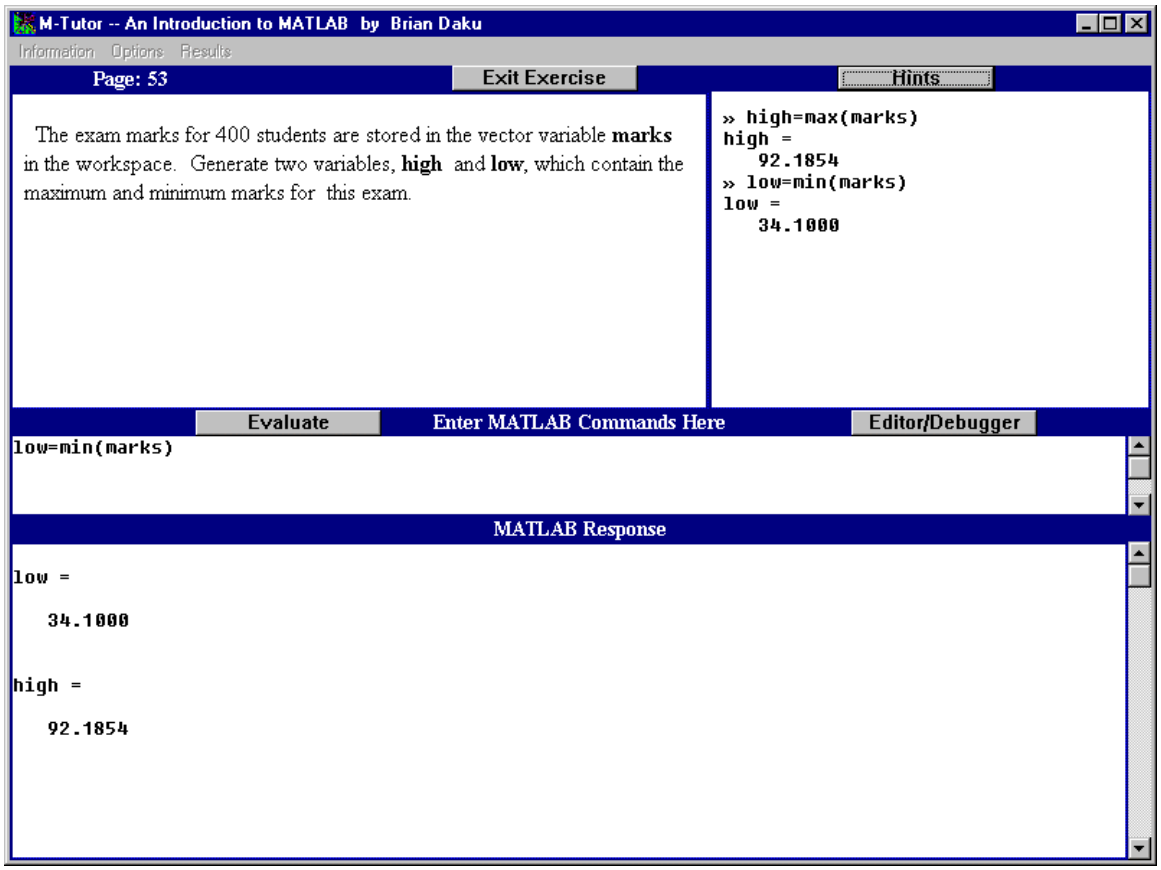

Fig. 2. Exercise Window from the MATLAB Tutorial.

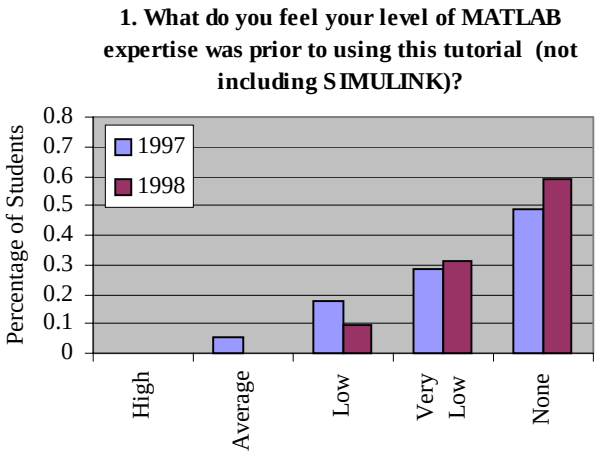

Fig. 3. Survey Question 1.

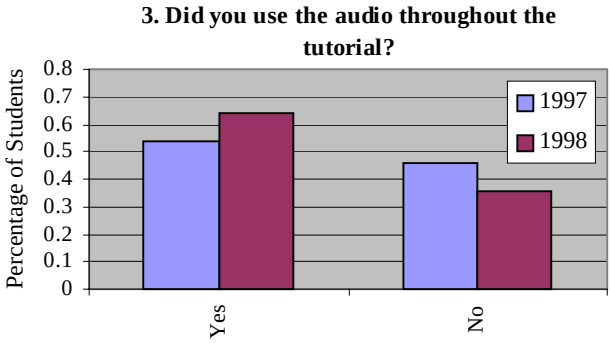

Fig. 4. Survey Question 3.

The students had the option of turning the audio off, if they so desired, since each student had headphones that they could use to listen to the audio in the tutorial. The distribution of audio use is presented in Figure 4. Verbal comments from the students concerning the audio were generally polarized, either they really liked it or they could not stand it. The students who did not use the audio felt that it just slowed them down.

B. Overall Impressions

The questions in this section of the survey related to how receptive the students were to this alternate approach in teaching. The questions are presented as statements and the student selects one of five choices, which gives a relative indication of whether they agree with the statement or not. The results of two of these questions are presented in Figures 5 and 6.

The results in Figure 5 demonstrate that for this group of students, learning MATLAB using a computer-based approach is preferable over a traditional lecture/assignment approach. Discussions with some of the students indicate the major reasons for this positive response are:

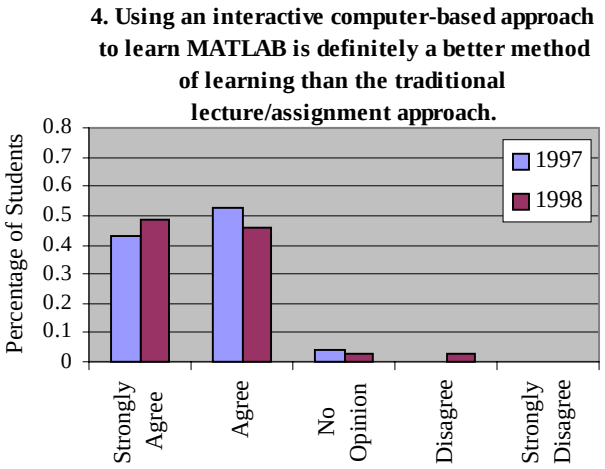

Fig. 5. Survey Question 4.

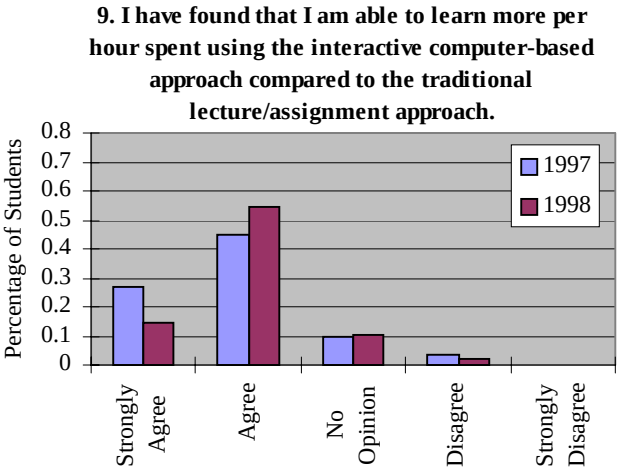

Fig. 6. Survey Question 9.

1. Immediate application of the MATLAB concepts using the Exercise window, which is not possible in a lecture/assignment approach. They also felt that having hints and the answer available for each of the exercises was very beneficial.
2. Freedom to go through the tutorial at their own pace as opposed to the lecture presentation, which is defined by the instructor.

The results in Figure 6, show that students believe that their rate of learning is higher for a computer-based delivery. This may be an important benefit considering the large amount of material that has to be covered in an undergraduate program.

C. Detailed Impressions

This section of the survey focused on the details of the tutorial implementation. Many of the questions are related to the components of the design process, such as pedagogical model, navigation, content and objectives.

The questions that relate to the pedagogical model provide student feedback on the methods used in the audio presentation and exercises. Verbatim-text audio was experimented with in this tutorial and the statement in Figure 7 was used to obtain some feedback. The results, which are

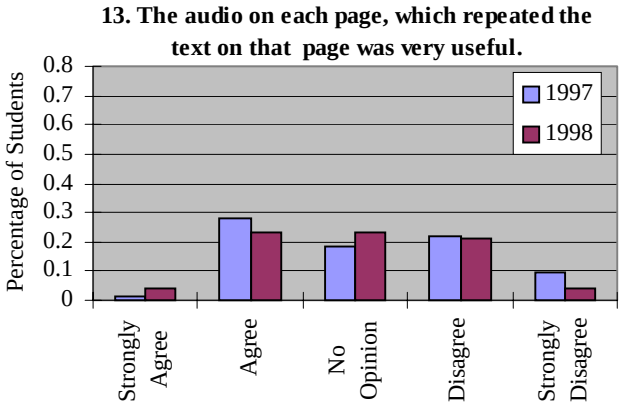

Fig. 7. Survey Question 13.

likely correlated with different learning styles, are spread across all of the possible responses, with more students disagreeing than agreeing. Thus it appears that including verbatim-text audio is worthwhile for some students, but for others, having the option to disable the audio is a requirement.

Figure 8 deals with using audio to describe the content of hotword boxes. The results here show that the majority of students liked this approach with a small percentage disagreeing. Comparing Figures 7 and 8, it should be obvious that controls for verbatim-text audio and hotword audio must be independent. The student should be able to disable either one or both forms of the audio.

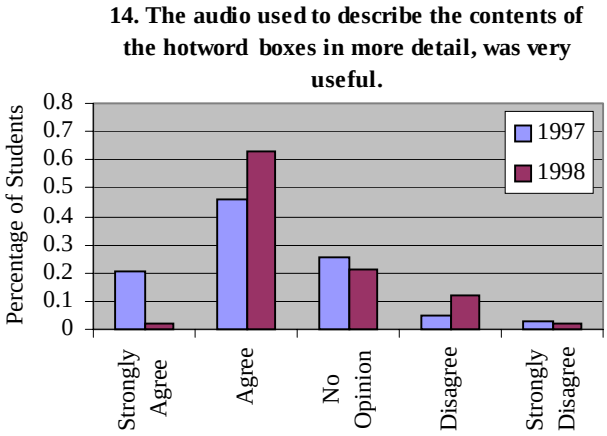

Fig. 8. Survey Question 14.

The statement in Figure 9 evaluates an alternate method, as opposed to continuous audio, for delivering the audio. The results indicate that hotword driven audio may be a useful feature for some students. Thus this feature is worthwhile including in the tutorial, but the user must have the option of selecting either continuous audio or hotword driven audio.

The results of the previous three questions indicate that

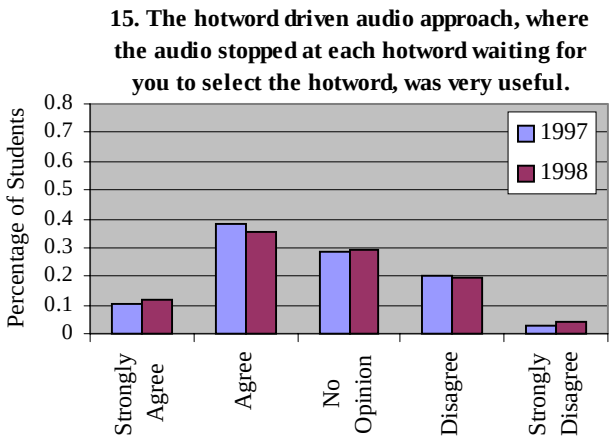

Fig. 9. Survey Question 15.

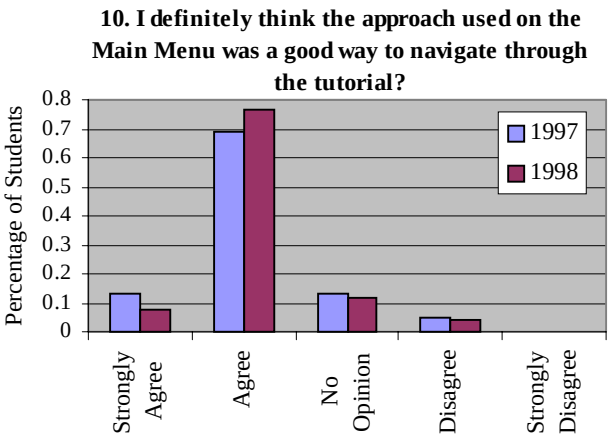

Fig. 11. Survey Question 10.

using audio for computer-based instruction is very beneficial for some users, but there must be versatile options for selecting the audio. The students can then select the options, which best fit their learning needs.

The approach used in the tutorial exercises was also evaluated in the student survey by comparing it with the traditional method of just assigning questions. The results of this statement are shown in Figure 10. The response here is very positive, the students definitely prefer the method used in the specially designed exercise window. The approach used in the delivering the exercises is one of the unique advantages of this computer-based tutorial over textbook tutorials.

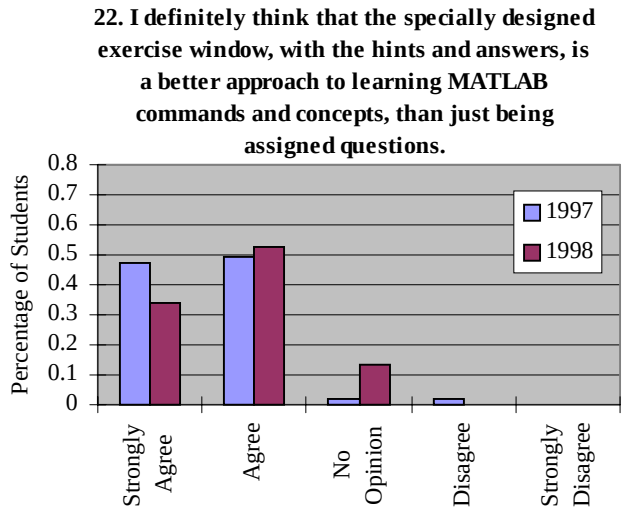

Fig. 10. Survey Question 22.

The next component of the design process is navigation. These questions attempt to assess whether the guiding principles used in designing the navigator were fulfilled. The question and results, shown in Figure 11, dealt with using the main menu to access the tutorial pages. As previously stated, the main menu consists of section heading hotwords, which when opened displayed the subsection heading hotwords, which in turn contained the actual page hotwords which took the student to that page. The next question, shown in Figure 12, evaluates the student response to the navigator buttons located at the top of the window. The results shown in Figures 11 and 12, were

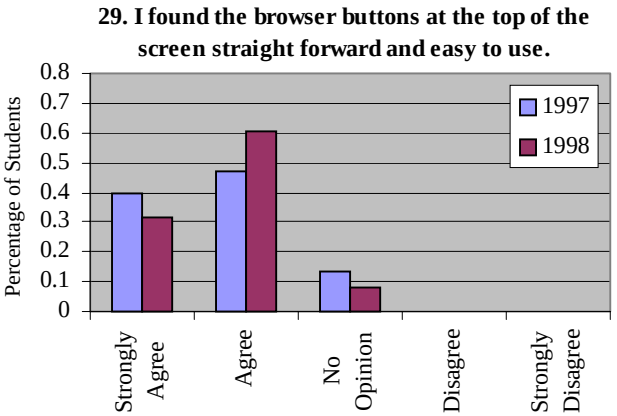

Fig. 12. Survey Question 29.

positive indicating that these were acceptable methods for navigation.

The last navigation question is more general, focusing on whether the students felt they had complete control over the tutorial. The results, which are positive, are shown in Figure 13.

The results of the previous three figures indicate that the design of the navigator appears to be successful. The students obviously feel comfortable using the navigator, which was a required design goal.

The question presented in Figure 14 relates to the content component of the design process. As the results indicate, all of the students agree or strongly agree that the content presented was clear and easy to follow.

The last question relates to the goals/objectives component of the design process. This question, shown in Figure 15, attempts to assess whether the students feel they are confident enough to use MATLAB after completing this portion of the tutorial. Since the students only completed

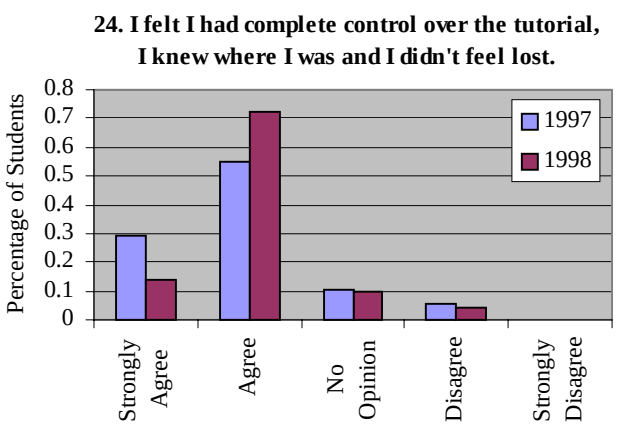

Fig. 13. Survey Question 24.

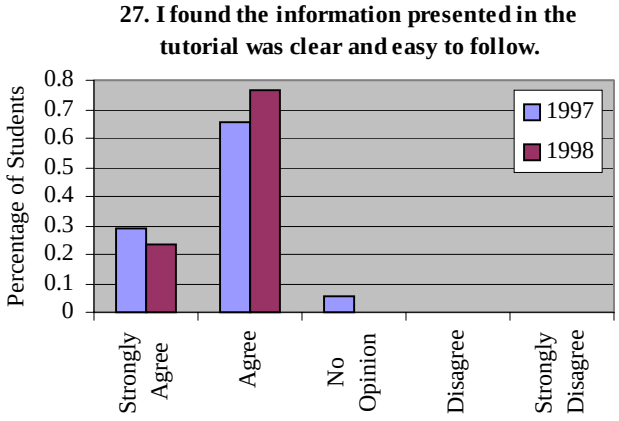

Fig. 14. Survey Question 27.

the portion of the tutorial up to plotting, the question asked if they are confident enough to plot a graph, which involves using the vector representation. The results were very positive, but of course, it does not assess the complete tutorial.

V. Conclusions

This paper describes the implementation of an interactive computer-based tutorial. It presents a summary of the design process and details of the actual implementation. Finally, it presents some student evaluation results, which assess some of the design and implementation features. These results also indicate how receptive the students are to this alternate approach to teaching.

In the tutorial, two of the unique features are the audio and the exercise window. The audio presentation received some mixed results from the students. These results are likely correlated with different learning styles. It appears that audio is beneficial for a portion of the student population and thus audio should be included when developing computer-based applications. The self-contained exercise window, which includes hints, example solutions and a background interface to MATLAB, was well received by the

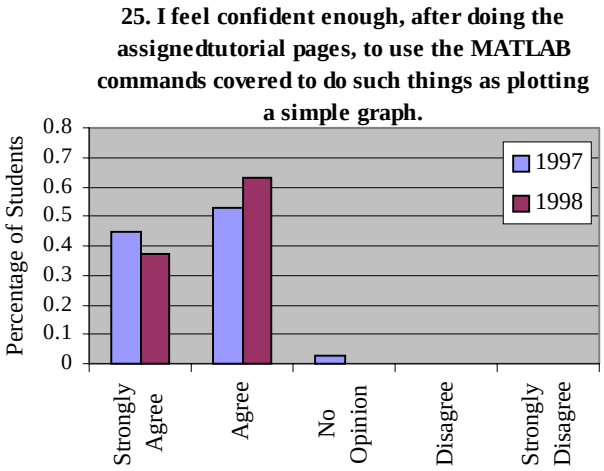

Fig. 15. Survey Question 25.

students. They felt that this was a much better approach than traditional assignments for reinforcing the concepts taught.

Since this project was a first attempt at computer-based instruction, there was some experimentation with various presentation techniques. The techniques used and the corresponding student feedback should provide some useful guidelines for others who are considering computer-based instruction. For example, when developing an interactive computer-based tutorial it is necessary to provide a wide range of selectable options that a student can use to tailor the tutorial to their learning needs. This is demonstrated for the use of audio, where only a small group of students felt that verbatim-text audio was useful, but a larger group of students felt that hotword audio was useful.

An important result of this work is that students appear to prefer this alternate computer-based approach to teaching when compared to the traditional lecture/assignment approach. They also feel that it is a more efficient way of learning. These, of course, are subjective results but they do indicate that this is a worthwhile area to explore.

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