Evaluation of Student Preferences and Learning Outcomes of Computer Based Teaching for a Manufacturing Processes Laboratory

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Abstract

Studies conducted by a number of investigators indicate that there are no negative outcomes when computer-based teaching (CBT) is used in place of or in conjunction with a traditional lecture. We performed three studies concerning student preferences and learning as a function of the instructional design and delivery of CBT modules. The studies were conducted in conjunction with the development of twenty-one CBT modules for an Introduction to Manufacturing Processes laboratory that emphasized metal removal. Study results indicate there is no statistically relevant difference in learning between students using material presented with traditional multimedia (35mm slides and cassette tapes) and the identical material presented with digital multimedia.

Engineering students' preferences for interface design and audio and visual information presentation are also presented. The interface design, overall, benefited greatly by employing the talents of technical writing majors.

The most important result is that learning outcomes of a reader-driven CBT module were found to be statistically lower than those associated with author-driven CBT module, especially for average and below-average students. These results suggest that if students must absolutely understand material, e.g., laboratory safety, the CBT should be author-driven. Based on these results, we speculate that average and below average engineering students are more linear learners. A hybrid scheme, where information presentation transitions from an author-driven to a reader-driven environment may help weaker students develop better non-linear, open-ended problem solving skills.

Introduction

Studies conducted by a number of investigators indicate that there are no negative outcomes when computer based teaching (CBT) is used in place of or in conjunction with a traditional lecture. Bengu and Swart[1] and Sears and Watkins[2] have described learning modules developed for use on the World-Wide Web (WWW). Cobourn and Lindauer,[3] Mosterman et al.,[4] Harger[5] and Dobson, et al.[6] have described additional learning modules for a variety of engineering programs developed with various authoring software. The authors of References 3 through 6 distributed questionnaires to their students in order to assess student receptivity to the modules. All noted favorable responses from students.

Other investigators have developed CBT modules and assessment schemes to test student learning. Flori et al.[7] developed a CBT module entitled "BEST" Dynamics, and Bailey, et al.[8] developed a CBT module on phase diagrams in a basic materials course. Both studies indicate that CBT is as effective or better than traditional lectures.

Wallace and Mutooni[9] present a good review of other CBT projects, especially those developed for use on the WWW. The purpose of their study was to design a pedagogical framework for teaching via the WWW, implement a lecture in that framework, and then evaluate its effectiveness compared to a classroom lecture. Performance on a project was evaluated for students who attended a classroom-based lecture compared with students using the CBT module. The average performance of students who received web-based instruction was higher compared with those who received traditional classroom instruction. The students spent roughly as much time on the CBT module compared with time in lecture. The CBT students indicated they valued the ability to pace their learning.

The above investigations suggest CBT is an effective learning tool. With this point in mind, we decided that the instructional design and delivery of CBT modules should be studied in more detail to determine what is most effective for engineering students. In this paper, we present the results of three studies concerning student preferences and student learning as a function of the instructional design and delivery of a CBT module. The studies are based on pre-laboratory learning modules developed for an introductory manufacturing processes course. A multidisciplinary team, composed of students and faculty from English and engineering faculty, developed these modules.

We focused our research on CBT modules for engineering students on three areas. First, we assessed comparative student learning with traditional multimedia (35mm slides and cassette tapes) and digital multimedia. Second, we examined student preferences for interface design and audio and visual information presentation. Finally, we assessed student learning as a function of the instructional design of the CBT module.

Background

Clark and others argue there is no compelling casual evidence that media or media attributes influence learning in any essential way.[10] He argues that "design" technologies determine the necessary information and objectives that provide an adequate learning environment that influences student achievement. This is not to be confused with Clark's term, "delivery" technologies, which he feels are necessary to provide efficient and timely access to the "design" methods and environments. We note that the investigators in Reference 9 claim to have found a difference in student performance as a function of the "delivery" technology. Hence, one topic we decided to investigation was an assessment of student learning as a function of traditional multimedia (mixed media in a non-digital format) when compared with digital multimedia.

The second topic of interest was student preferences of certain design features of the interface. For example, do students prefer to automatically have the audio play when they enter a new page or do they prefer to push a button to activate audio? Preferences were of interest to us largely because CBT modules take considerable time to develop. Wallace and Mutooni note the initial human resources needed to create their web-based learning module were roughly five times greater than those needed for developing the classroom lecture. Cates defines a production ratio as the relationship between the number of hours it takes to design and create an computer-based instruction to the one hour it takes the learner to complete it.[11] In a study with novice multimedia developers (graduate students in instruction technologies) using an authoring software package, he noted an overall production ratio of 589:1. Considering the time investment required for producing a CBT module, it is valuable to have an interface design in mind prior to construction of modules, which includes an understanding of student preferences in usability and aesthetics.

The third topic of interest was an assessment of student performance in a "reader" controlled environment compared to an "author" controlled environment. In a reader controlled environment, the learner makes decisions about what sections to study, at what rate to study, and/or what paths to follow through interactive materials. This is in contrast to an author-controlled environment where the CBT module is designed so that the learner is presented material in a prescribed order, controlled by the author. Reader controlled is analogous to the "parallel" environment of Wallace and Mutooni while author control is analogous their "sequential" environment. Much has been written on this topic within the instructional technology community and numerous studies have been conducted.[12] The results are inconclusive and perhaps not relevant for engineering students since learners used in these studies are typically K-12 students or undergraduate teacher preparation students.

Manufacturing Processes Laboratory CBT Modules

The Mechanical and Aerospace Engineering Department at Utah State University offers a sophomore-level course entitled Manufacturing Operations - Fundamentals. Material removal processes are emphasized and a survey of other topics such as casting, extrusion, forming, quality assurance, automation and computer-integrated manufacturing is also offered. The course is five quarter hours in length: 3 hours of lecture and 2 hours of laboratory. In the laboratory, the emphasis is on metal machining and machine tool operation. The intent is to provide students with hands-on exposure to metal product manufacturing.

The late Professor Carl Somers of USU developed a series of pre-laboratory learning modules using cassette tape and 35mm-slides. The learning modules were used to enhance laboratory safety by introducing laboratory material. They described in detail how to use each machine and then provided a step-by-step explanation of how to produce the various workpieces required of the students. These modules were the basis of the twenty-one CBT modules in use today. The audio and visual content was revised as necessary to reflect the present laboratory. Prior to attending a laboratory session, the students are asked to work with a CBT module, available on CD-ROM in the USU library, complete a worksheet, and submit the worksheet to the lab instructor before they are allowed to work on the machines. The laboratory instructor also provides a brief review of the module content to ensure laboratory safety.

Digital and Traditional Multimedia Comparison

The modules original developed by Somers have been an effective, if somewhat cumbersome heuristic. We did not want to create a new teaching environment that we could not demonstrate was at least as effective as the old. Hence, we compared information acquisition among students using a traditional module to that of students using a CBT module. In this study, we made every effort to make the resources as nearly identical as possible -- we used the same graphics, voice, content, and page count. The only important difference in these media is an outline of the audio we were able to add to the digital module, not possible in the traditional module.

We randomly divided a class of 38 students into two groups, Group A studying machine shop safety using a traditional module, Group B studying the identical topic using a CBT module. Students examined the topics while completing identical worksheets. Immediately after studying their topics, students took a quiz. Due to the small sample size, we employed a student's *t* distribution.[13] After grading the quizzes from the two groups, we found no significant difference between the average test scores between the two groups at an .01 level of significance. Study results are shown in Table 1. To ensure we had randomly distributed students between the two groups, we compared their final grades at the end of the term. We found no significant difference between the average final grades for the two groups at a 0.01 level of significance.

Table 1. Comparison of data for two groups given identical assignments but different multimedia environments.

<table>
<tr><th>Group</th><th>Tool Used</th><th>Group Size</th><th>Standard Deviation</th><th>Average Misses</th><th>Level of Significance</th><th>Conclusions</th></tr>
<tr><td>A Quiz Score</td><td>Traditional Multimedia</td><td>14</td><td>0.751</td><td>1.71</td><td rowspan="2">0.01 (99%)</td><td rowspan="2">Groups A and B quiz scores are not statistically different.</td></tr>
<tr><td>B Quiz Score</td><td>Digital Multimedia</td><td>16</td><td>0.774</td><td>1.68</td></tr>
<tr><td>A Course Grade</td><td>Traditional Multimedia</td><td>14</td><td>1.75</td><td>3.35 (Course GPA)</td><td rowspan="2">0.01 (99%)</td><td rowspan="2">Course grades for groups A and B statistically the same.</td></tr>
<tr><td>B Course Grade</td><td>Digital Multimedia</td><td>16</td><td>1.68</td><td>3.25 (Course GPA)</td></tr>
</table>

Our results are consistent with the findings of Clark – the delivery method is not important if the instructional designs of two different media are the same. This is in contrast to the findings of Reference 9. Wallace and Mutooni noted their students liked the CBT module because they could pace themselves and not be embarrassed by spending too much or too little time on one topic when compared with the lecture presentation. In our study the students could pace themselves with either delivery system which may account for the extent to which are results differ from Wallace and Mutooni.

Preference Studies

These CBT modules were co-developed by members of English and engineering faculty. During spring term, 1995, three different teams of technical writing students were assigned the task of developing an interface. The interfaces were then tested on engineering students for usability and aesthetics during fall term, 1995. Of the digital multimedia interfaces, one used an operator's panel metaphor and two used textbook page metaphors. Shown in Figures 1, 2 and 3 are samples from each module.

Modules 3 and 5 both contained audio and visual components. In Module 3, each page contained a voice describing the material; every time students entered the page, they automatically heard the voice. In Module 5, students heard the voice only after pressing the "play sound" button. In Module 3, audio and written texts were identical. In Module 5, audio was comprehensive while written text was in outline form. In Module 3, the images automatically enlarged to nearly full screen while the voice described them ("pop ups"), then students could reduce images to a smaller, final size. In Module 5, images enlarged to larger size only if students clicked on them. Modules 3 and 5 are in sharp contrast to Module 11 which contained only an image and text. The image could not be enlarged and there is no audio describing the material to be learned.

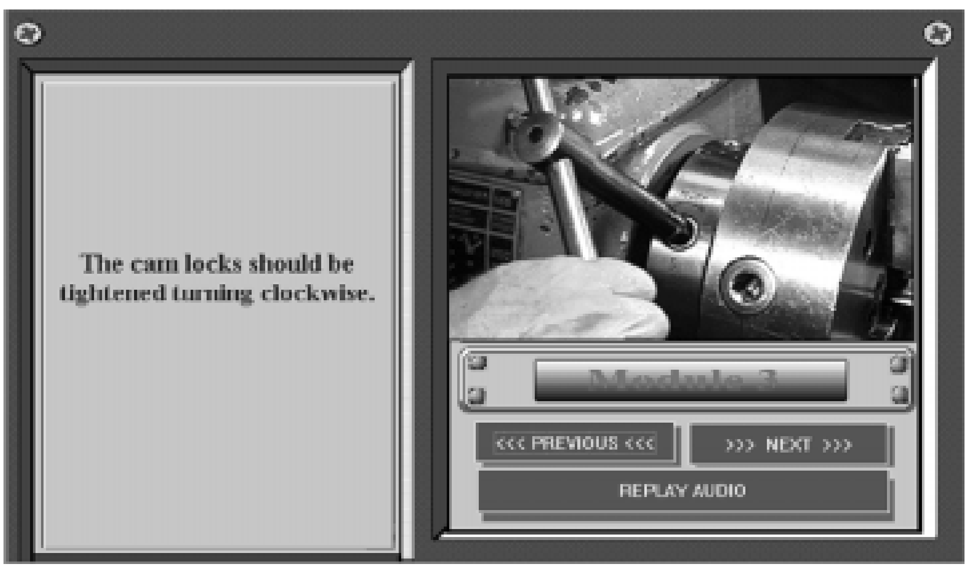

Figure 1: Module 3 -- Operator's Panel Metaphor.

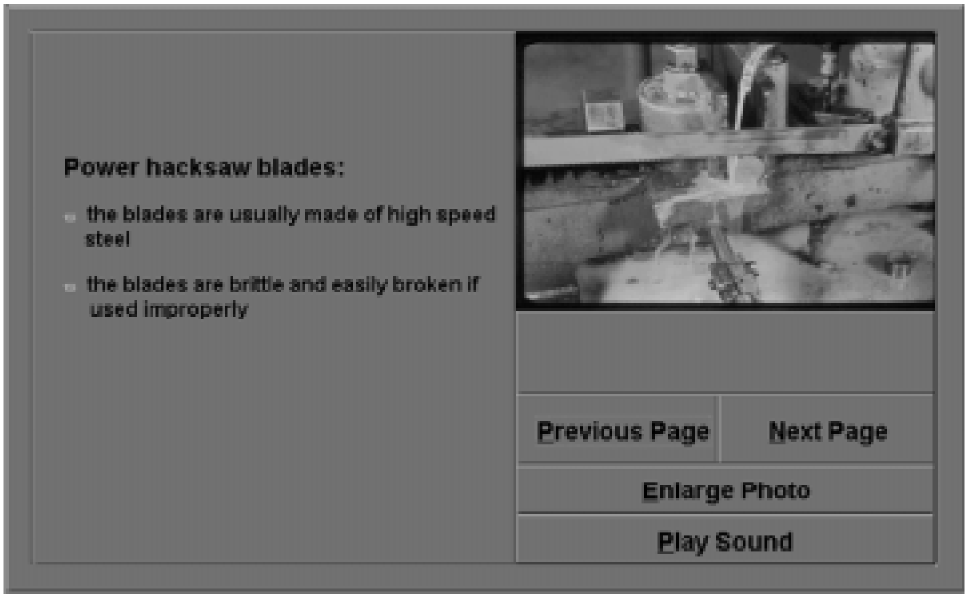

Figure 2: Module 5 – Textbook Page Metaphor with Sound.

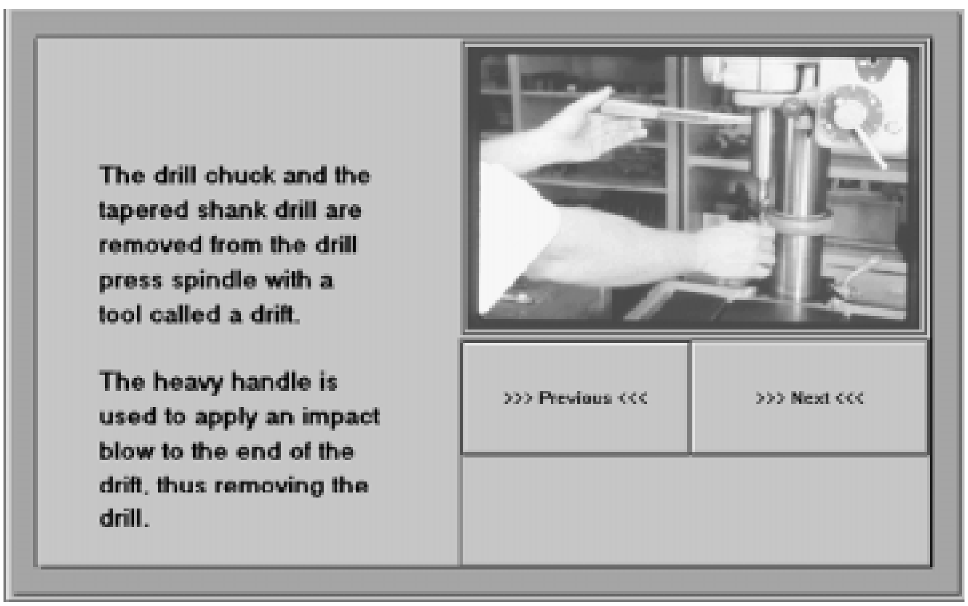

Figure 3: Module 11 – Textbook Page Metaphor without Sound.

Traditional Multimedia Compared with Digital Multimedia

In the fall of 1995, thirty-eight engineering students were first asked about their experiences with CBT modules. They noted considerable experience with computer games and even interactive encyclopedias, but none had any experience with CBT. The students were then asked to compare the three interfaces in Figures 1, 2, and 3 (Modules 3, 5 and 11 respectively) with the traditional multimedia interface of 35mm slides and cassette player. The students had completed Modules 1 and 2 using the slide-tape interface. When compared with traditional multimedia, roughly 79% of the students found the Module 3 and 5 interfaces much more useful or more useful; 18% of the students found the interfaces about the same and 3% of the students found the interfaces less useful. Interestingly, only 66% of the students found the Module 11 interface much more useful or more useful when compared with the traditional multimedia, 18% still found Module 11 interface about the same as the traditional multimedia and 16% found the Module 11 interface less useful than the traditional multimedia. On the whole, students overwhelmingly preferred the digital multimedia to the traditional multimedia. However, the students found the interfaces with multiple media – visual, text, and voice -- preferable to the very "textbook-like" interface of Module 11.

One reason the students may have preferred the digital multimedia is ease of use. We observed a large number of students working their way through both the traditional and digital multimedia. We found them to be very task oriented – their objective was to complete the worksheet that was required before they could participate in a laboratory experience. If they missed a particular worksheet question, they could more easily move backward in the digital multimedia environment by simply clicking a button compared to having to reverse the cassette tape and then stopping the tape at just the right spot for the missed information.

Audio Preferences

The three modules presented a variety of audio options. In Module 3 the students automatically heard the instructor's voice describing the material every time they entered a page. They could replay the audio by pushing a button. In Module 5 the students had to push a button to hear the audio and Module 11 contained no audio. 71% of the students preferred the automatic voice of Module 3 when compared with the option in Module 5. 94% of the students found the option to reply the audio very useful or useful. All students found the audio easy or very easy to understand. The students were asked after completing Module 11 whether they "missed the audio." 55% of the students really missed or missed the audio, 29% of the students missed the audio somewhat and 16% of the students did not miss the audio. The results of the surveys suggest students prefer multiple media – both audio and visual material. Furthermore, they do not feel the need to control all aspects of the media, the majority of students preferred the automatic voice of Module 3 which played as they entered a new page.

Visual Preferences

All interface designs included an image that accompanied the audio and text information on the page. In Module 3 the graphical image enlarges ("pops up") automatically to nearly full screen.

The students can reduce the image by pressing any key. In Module 5 the image enlarges only if the students click the "enlarge image" button. Module 11 has no "pop ups." A vast majority of the students felt the "pop ups" helped clarify the images in the smaller picture. However, 72% of the students preferred to click a button in order to produce an enlarged picture rather than have the picture automatically enlarge when they enter a new page. These results are an interesting contrast to the audio results. The students want to make their own decisions when it comes to the enlargement of the graphics, but were content to have the sound play automatically when entering a new page.

Interface Preferences

Although the students were somewhat divided over whether they needed sound and popup graphics, the more graphics and sound a digital module contained, the higher the students rated it. In trying to establish an integrated, overall preference, we asked the students "which module do you like the most?" The students ranked Module 3 highest and Module 11 lowest. When they answered the reverse question, "Which do you dislike the most?" the students demonstrated a strong dislike for Module 11; few students disliked Module 3. We conclude that students preferred the more meaningful and recognizable operator's panel metaphor when compared with the less identifiable and nondescript textbook page metaphor. We also conclude students prefer more sophisticated sound and graphics.

Final Module Design

The final module design was developed based on analyses of the students' preferences and is shown in Figure 4. The control panel interface was selected – the primary background color was shifted from green to blue to reflect USU's colors. The audio instruction begins automatically when a student enters a new page. The students can enlarge the graphic image by clicking on it. They can move forward, backward, replay audio or exit the book.

The modules run smoothly on a 75 MHz Pentium processor machine with 16 Mbytes of RAM. A CD drive and a standard sound card are also required. We employed the following software to complete the modules: ToolBook™ by Asymetrix to create the learning module, Sound Forge™ by Sonic Foundry with a hiss reduction plug-in to record and edit sound, and Adobe Photoshop™ to process images. Images were scanned from 35-mm slide or captured with an electronic camera. Images were scanned or captured at about 1 Mbyte resolution and then reduced to about 300 kbytes and imported into ToolBook.

Reader-Control Compared With Author-Control Instructional Design

If one assumes that at the very least digital media do not harm learning, the question arises, "Which digital media best enhance learning?" In an effort to compare as few differences as possible, we created two modules with identical content, except that one is author-driven while the other one is reader-driven. Both modules contained identical text and graphics. Neither module contained sound. Module A, shown in Figure 5, is an author-driven design -- students may go forward or back but may make no other navigational choices. Module B, shown in Figure 6, is a reader-driven design. Students can make five navigational choices as they enter the document, and additionally, parallel choices on many, but not all, pages. First we developed Module B with the intent that the material within each sub-module be independent of other material in other sub-modules. For example, understanding the section on pneumatic vise control should be independent of understanding the section on the CNC programming language. Then we constructed Module A by simply linking the sub-modules of Module B together in a linear fashion.

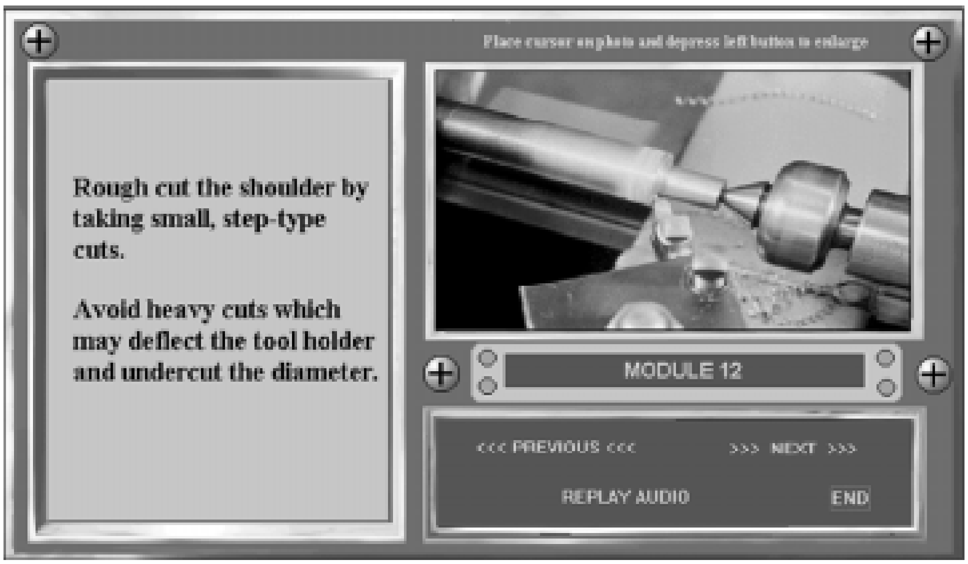

Figure 4: Typical Page of Pre-Laboratory Instruction Module.

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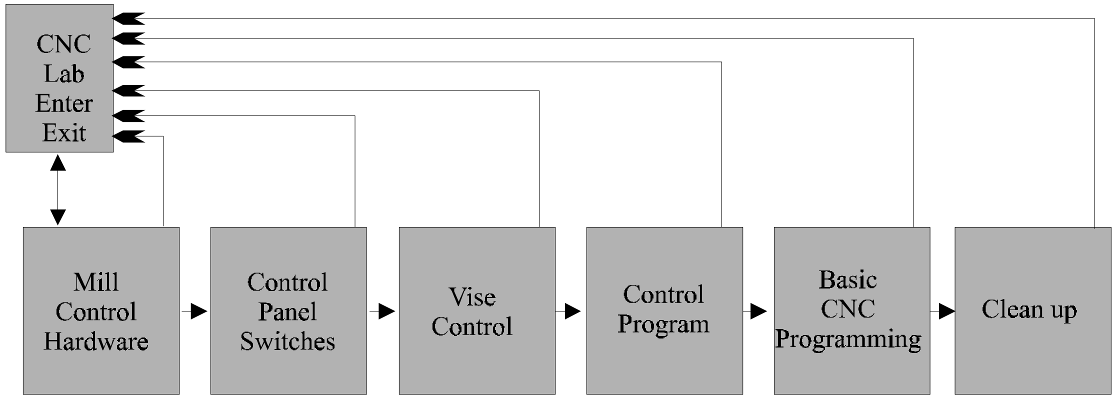

Figure 5: Schematic of Author-Driven Module A

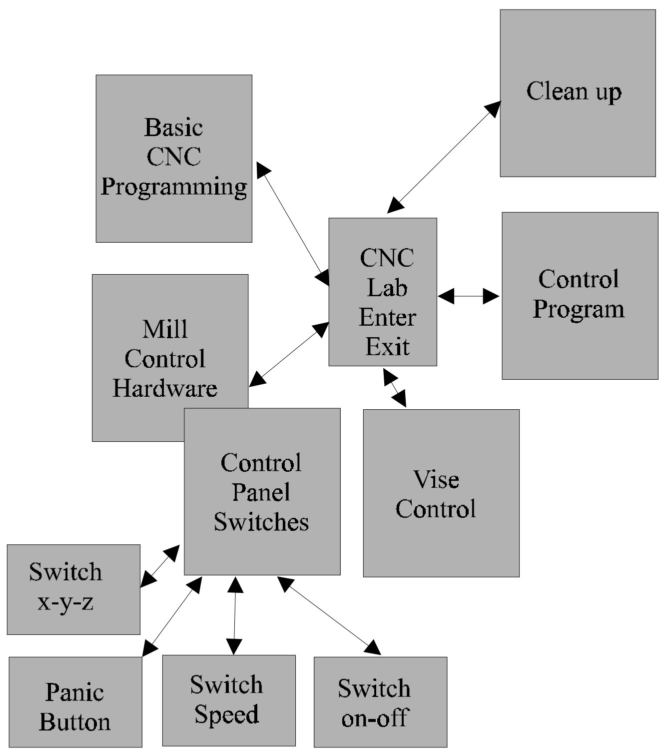

Figure 6: Schematic of Reader-Driven Module B

During the fall term, 1996, 38 students were randomly divided into two groups, each half was assigned either Module A or B. Students worked their ways through the modules filling out a worksheet as they progressed. This helped insure that all students visited all available information. Once they completed the module, students took a quiz to assess their understanding of the material. We also observed the students working with the modules and noted that students using the author-driven module typically took approximately half the time of students using the reader-driven module.

Again because of group size we used a *t* distribution. We determined that there was a significant difference in the average scores of the two groups at 0.01 level of significance. The students working with Module B did worse, on the average, on the quiz. Study results are shown in Table 2. To ensure we had randomly selected groups, we once again looked at their final grade in the course. There was no difference in the average, final grade of the two groups to a 0.01 level of significance.

Table 2. Comparison of groups A and B using author-driven and reader-driven control.

Group	Tool Used	Group Size	Standard Deviation	Average Misses	Level of Significance	Conclusions
A Quiz Score	Author Driven	19	0.795	1.684	0.01 (99%)	Groups A and B quiz scores are statistically different.
B Quiz Score	Reader Driven	19	0.736	3.947		
A Course Grade	Author Driven	19	0.794	3.3 (Course GPA)	0.01 (99%)	Course grades for groups A and B are statistically the same.
B Course Grade	Reader Driven	19	0.735	2.8 (Course GPA)		

We found these results surprising and decided to take a closer look at the differences in learning between the two groups. Breaking these two large groups into smaller groups, based on grade points, was not part of our original experimental design and so the following results should be viewed as preliminary. If we break the students out by the final grades they received in the class, we discover that "A" students in both groups show no statistical difference in performance on the quiz. "B" students, on the other hand, missed an average of 1.2 questions on Module A as opposed to 4.2 from Module B—this represents a statistically significant difference on average test scores at a 0.05 level of significance. "C" students studying from Module A missed an average of 2.6, while "C" students studying from Module B missed an average of 4.5 questions--this represents a statistically significant difference on average test scores at an 0.2 level of significance. Given this high level of significance, the comparison of the grades for the "C" students indicates a trend at best. However, in trying to understand learning differences this is valuable information.

These results imply that there is a difference between information acquisition in reader-driven compared with author-driven instructional design. It appears “A” students work equally well in either environment. Although Wallace and Mutooni did not observe whether their students used the web-based module in an author- or reader-driven fashion, we suspect it did not matter. Almost all students enrolled in their program would be “A” students at USU. However, we were interested to note that “B” and “C” students (at USU, a “B” student is an average student and a “C” student is a below-average student) appear to learn the material better in an author-driven environment.

The above study has important implications for developing CBT tools. If all students must absolutely understand material, e.g., laboratory safety, the CBT should be developed as an author-driven tool. On the other hand, these results suggest that “average” and “below average” engineering students may be very task-oriented, linear thinkers. If the educator’s goal is to develop nonlinear, open-ended problem solving skills, a reader-driven tool may be ultimately more effective -- or, possibly, a hybrid scheme, where the student is initially exposed to an author-driven environment and then the control is slowly transitioned to a reader-driven environment. At a minimum, these results indicate more research on the nature of engineering students’ responses to various CBT instructional designs is important.

Conclusions

Research to date suggests there are no negative outcomes when CBT is used in place of, or in conjunction with, a traditional lecture. To better understand the design of an effective CBT tool for engineering students, we conducted three studies to evaluate student preferences and learning in various CBT environments.

Results of our first study indicate there is no statistically relevant difference in cognition between students using traditional and digital multimedia learning tools – all other things being equal. At least for engineering majors, a 35mm-slide and cassette tape is as an effective media for instruction as digital multimedia. Our results are consistent with the findings of Clark and initially may seem at odds with the results of the study done by Wallace and Mutooni. However, there is at least one important difference between the two studies that could account for the differences. Although Wallace and Mutooni made every effort to keep the CBT module and the lecture material the same, in the case of the lecture, the instructor controlled the pace of information presentation. The students controlled the pace of information presentation when utilizing the web-based module.

In our study, the content of the traditional multimedia module and the digital multimedia module were identical. The primary difference was whether the student examined them on a projector screen or on a computer monitor. The students vastly preferred the CBT environment – it was easier to use, especially if we remember that the students move back and forth through the module as they completed a work sheet. As developers of learning tools, we also vastly prefer the CBT environment. In particular, it is much easier to update or modify material. However, existing modules utilizing 35mm slides and cassette tapes should not be abandoned if the content is still current. Also, if an institution does not have the hardware and software necessary for CBT production, the slide/tape tool is a reasonable alternative.

We looked at two different interface metaphors and determined that engineering students prefer a visual metaphor that resembles an operator's panel to a textbook-like page. We compared approaches to introducing audio to CBT modules and determined that students prefer to have sound automatically available. We compared approaches to presenting "pop up" graphics and found that students prefer calling them up rather than having them open upon entering a page. The interface design, overall, benefited greatly by employing the talents of technical writing majors. These students and faculty were, in general, more concerned with the "look and feel" of the interface than the engineering faculty member.

In the final test of this study, we determined that at least for this group of students, reader-driven CBT was statistically less effective than author-driven CBT. We have some indications that the good students did well in either environment. However, average and below-average students struggled with the reader-driven environment. This is a significant outcome. First, if all students must learn the material, e.g., laboratory safety, the CBT should be of author-driven design. These results also highlight the importance of more research in this area focused on engineering students and the types of materials they must learn.

Another outcome of this study is a suggestion that average and below-average engineering students are linear, sequential learners. They appeared to be very task oriented – seeking only enough information to complete a work sheet. These qualities are not surprising, we have probably seen similar behavior in students in a traditional lecture class. One of our greatest challenges is to develop open-ended problem solving capabilities with students where non-linear, parallel, "reader-driven" thought processes are required. This study, albeit in a slightly obtuse fashion, suggests a technique. Perhaps CBT tool developers should focus on hybrid modules that transition from "author" driven to "reader" driven environments. Although, initially more frustrating, a "reader" driven environment may help average and below average engineering students develop more open-ended problem solving skills.

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Biographical Sketches

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