An Empirical Study of Student Interaction with CD-based Multimedia Courseware

W. Burleson, W. Cooper, J. Kurose, S. Thampuran, K. Watts

Department of Computer Science / Department of Electrical and Computer Engineering
University of Massachusetts Amherst

Abstract

The CD-MANIC project is developing a multimedia courseware system that combines the use of CDs for bandwidth-intensive content with periodic Internet connections for updates, logging, assessment and access to Internet resources. Class materials distributed by CD include a semester's worth of lectures (recorded during an earlier offering of the class) in the form of high quality audio/video synchronized with the display of class notes, overheads, and other in-class material. The CD-MANIC interface provides interactive controls for navigating course material, a multiple-view index over this material, a search facility, and (in some cases) access to an electronic copy of the complete course textbook.

CD-MANIC also includes a logging facility that tracks students' interactions locally and then uploads logged student activity to a central site for analysis. In this paper we present logged student activity for approximately 50 students who used CD-MANIC for a full semester in a variety of settings, including off-campus students who used CD-MANIC as their sole means of obtaining classroom lecture material, and on-campus students who used CD-MANIC as an adjunct to another instructor's teaching of the course. We provide a brief overview of CD-MANIC and the logging facility and then report on gathered data. We discuss our findings on the extent to which students viewed material in long-term, continuous play modes versus short-term, highly-interactive modes; the manner in which students navigate through course materials; and student use of the various components (audio/video, slides, index, and electronic book) available.

We describe how results are being used to evaluate the existing version of CD-MANIC and develop future versions which more closely meet different student's needs.

1. Introduction

As computing, media-processing, and storage devices drop in price and become increasingly widespread, there has been increasing interest in their use in developing asynchronous, distance-based education software and content.. While there are numerous commercial and public domain systems being used for such purposes, there is little reported data on how students actually use such systems. Moreover, with the continuous, rapid change in technology comes a continuous,

rapid change in how these technologies are incorporated into distance-learning systems and consequently how students use such systems.

In this paper, we provide an empirical characterization of how students use an asynchronous, CD-based, multimedia distance-learning system known as CD-MANIC. CD-MANIC project is a courseware system that combines the use of CDs for bandwidth-intensive content with periodic Internet connections for updates, logging, assessment, and access to Internet resources. Class materials distributed by CD include a semester's worth of lectures (recorded during an earlier offering of the class) in the form of high quality audio/video synchronized with the display of class notes, overheads, and other in-class material. The CD-MANIC interface provides interactive controls for navigating course material, a multiple-view index over this material, a keyword search facility, and (in some cases) access to an electronic copy of the complete course textbook.

CD-MANIC also includes a logging facility that tracks a student's interactions locally and then uploads logged student activity to a central site for analysis. In this paper we present logged student activity for approximately 50 students who used CD-MANIC for a full semester in a variety of settings, including off-campus students who used CD-MANIC as their sole means of obtaining classroom lecture material, and on-campus students who used CD-MANIC as an adjunct to another instructor's teaching of the course. Our results show (i) that students are much more likely to move forward through the material than backwards (e.g., using CD-MANIC's Fast Forward, Next and Down commands much more frequently than their Rewind, Previous and Up counterparts), (ii) that more than half of the material is viewed in an automatic (rather than manual) mode, in which the system automatically sequences through synchronized slides, audio/video and textbook sections (iii) that audio/video playout is an important component of the system, generally in use more than 60% of the time, and (iv) that continuous audio/video playout tends to last for relatively short periods of time (e.g., less than 10 minutes) before being interrupted by the student. Overall, the results point to a high degree of student interactivity with the system. We also report briefly on student evaluations of CD-MANIC which indicated both enthusiasm for the application and a preference for CD-MANIC over traditional VHS tape delivery.

The aim of this paper is to understand how students interact with a multimedia courseware system like CD-MANIC and not to evaluate their performance or provide any evidence of improved learning. Although data was logged from the "Computer Networking" course offered in different schools during the Summer and Fall of 2001, this paper does not provide reasons for the variation in the manner in which students from different schools interact with CD-MANIC. This is because our data was based on a narrow spectrum of only 56 students. However, future work might include evaluating student performance as well.

The remainder of this paper is structured as follows. In section 2, we provide an overview of past work in this area. In section 3, we describe CD-MANIC's student activity-logging facility that was used to gather our empirical data. Section 4 describes our student population. Section 5 presents and analyzes our logged data. Section 6 concludes the paper and discusses directions for future research.

2. Related Work in this Area

A variety of multimedia courseware systems have been introduced by commercial and academic groups in recent years. One of the most ambitious has been the Classroom 2000 project at Georgia Tech[1] which uses a complex software infrastructure to capture the rich interaction that occurs in a typical university lecture. Classroom 2000 has a similar although larger goal than our CD-MANIC project but uses a web-based approach and a much more costly development infrastructure leveraging a specially equipped classroom. Both projects include video, audio, slides, search capabilities, and mechanisms for student interaction.

The Berkeley Multimedia Research Center (BMRC) has developed the Lecture Browser [12], a web browser based tool written in Javascript which provides remote students with streaming video and synchronized slides. The key features of the Lecture Browser include the ability to search text and browse media type (slides and video) independent of one another.

Another courseware system is the Just-In-Time Lectures[13] that is being developed at the Carnegie Mellon University (CMU). Digital video lectures are combined with high-resolution slides and presented using an interactive software program. Just-In-Time Lectures use e-mail to link students to their instructors, and the World-Wide Web to provide access to on-line information, including assignments, exercises, supplemental texts, and glossaries.

There exists a significant literature in developing and deploying student behavior evaluation systems. Computer-based training systems, and in particular web-based systems make logging of student behavior very easy and this has become a standard method of evaluating how students utilize various features. Early use of web browsers for distance learning was studied[2] and student behavior logs for digital libraries were presented[3]. A more ambitious use of student logging was a system[4] in which dynamic monitors written as Java Applets and VB script are used for Web-based logging of student and instructor behavior in a distance-learning environment. This work includes logging of timings and paths through instructional materials as well as performance on assessment instruments. Logs are used to dynamically classify students into groups using genetic/fuzzy algorithms to facilitate adaptive curriculum. The question of instructor behavior in a distance learning system was explored using a logging system[5], and address the popular question of whether teaching on-line takes more time.

Work by our group using the earlier web-based non-CD version[6] of MANIC used a web-logging system and defined some concepts used in this paper including the idea of a "student event" and a "student session". The study showed several non-intuitive results including (i) many students chose not to listen to audio, (ii) many students skipped forward rather than backward to repeat material, (iii) audio playout durations were rather short with nearly half of the audio playouts lasting less than 3 minutes before a Pause, Stop or Fast Forward (FF)/Rewind, and (iv) the courses were widely accessed in more than 100 countries.

3. Data Logging Infrastructure in CD-MANIC

In previous incarnations of our system called MANIC[6] (Multimedia Asynchronous Networked Individualized Courseware), data logging was a completely server side activity. This is due to

the fact that these older versions of MANIC were built using a client/server model where the server played a significant role in the delivery and presentation of course content. Since the server had knowledge of each request made via the client's web browser, it was a relatively simple task to document these actions in a server side log that could later be analyzed.

CD-MANIC was designed to allow the client side student to view bandwidth intensive multimedia content without the need for having a high bandwidth connection to the Internet. This was motivated largely by the fact that many students of MANIC have low-bandwidth connections to the Internet, and some students had difficulty viewing presentations that involved streamed low-bandwidth audio. For these students, connections to the MANIC server would sometimes be intermittent and disrupt the flow of the presentation. Clearly, such students would not be able to view similar presentations that stream higher bandwidth video. Additionally, upgrading MANIC to support video would introduce the possibility that students who were able to view streaming audio presentations may not be able to view higher bandwidth content with the same fluidity. CD-MANIC provides a reasonable solution by not requiring a high bandwidth connection or any connection at all, in order to view high bandwidth content. However, this de-coupling of the client-server model introduced the problem of no longer being able to log student behavior on the server side.
Our approach to overcoming the logging problem is twofold. First, the ability to log the student's behavior within the context of the application was built into CD-MANIC. Actions such as clicking on the slide index, resizing the application, searching, and selecting items from the application menu are recorded in the log file, along with a date and time stamp. Note that no personal information about the student is ever captured or recorded in the log. Students are uniquely identified using the serial number of their local hard drive. The second half of the problem is sending the data to a place where it can be retrieved and reviewed. This can be initiated either by the student through a menu item or automatically by the application. For the automatic case, CD-MANIC will determine if a certain period of time has elapsed without uploading log data and if so and a connection to the Internet exists, it will attempt to send the data to the log server.

This approach to capturing student behavior has the advantage of being able to capture data in a higher level of detail than methods used in previous versions of MANIC[6]. For example, server side logging cannot determine if the student resizes or moves a window. Another advantage to this approach is that it does not require a constant connection to the server in order to view course content. A student can be completely disconnected from the network, such as being on a plane or in a car, and their behavior can still be logged.

There are also several disadvantages to this approach. First, there is the potential that log data may never be retrieved from any students. For example, a student may only use the application when they are not connected to the network and so their logged data will not be sent to the server. Second, most of the behavior of a particular student may be captured and sent to the server but all of their behavior will not be sent to the server, since the student will usually perform some kind of logged action after each log upload. This amount of data may not be significant enough to be of concern. Third, it is possible for a single student to run the application on more than one machine. Since CD-MANIC does not attempt to identify a single student based on personal information and the uniqueness of a student is identified by the

uniqueness of their hardware, a single student has the potential to appear as multiple students in the log data. Despite these disadvantages, it seems that they do not significantly impact the data collection process due to the amount and diversity of the data that has been received by the log server.

Log data is recorded and stored locally on the client machine in a text file which is a series of variable length comma separated records. There are currently six primary types of events stored in the log data with the potential to support more event types in the future. These event types include records related to button clicks, clicks within the index, menu selections, searches, slide displays, and window events. Each record contains a date field, a time field, and a field that indicates what type of event is being logged, where the date and time are taken from the client machine. The button record contains an additional field that indicates which button was clicked. The index record contains information about which index was clicked, typically the slide index or search index, and a string that represents the actual text that was clicked. The menu record contains a field that indicates which menu item was selected and a second optional field that is used to indicate if the menu item is in a checked state, used only by menu items that can be selected. Search records contain a field that indicates how the search was initiated, a field for the search type to use, a field to indicate if the search was over slides or on an on-line book, and a field that contains the search string. The slide record contains a field for the slide number, a field for the bullet number, a field that indicates automatic or manual display of the slide, and a field that lists the time in milliseconds into the presentation the slide was displayed. Finally, the window record contains a field that indicates the type of window event logged and four fields that represent the top, left, width, and height of the window.

4. Student Population

To-date, CD-MANIC has delivered the "Computer Networking" course with Professor James. F. Kurose in a variety of settings. The first implementation of the course on CD-MANIC was with the Video Instructional Program[7] (VIP) at the University of Massachusetts Amherst. Courses being taught by faculty members before an on-campus student audience are videotaped and broadcasted by VIP. The videotapes are then delivered to VIP students across the country and the world, primarily providing continuing education to professionals in industry. VIP redistributes its courses along with many other universities through National Technological University (NTU). During the Summer of 2001 graduate students enrolled in "Computer Networking" (CMPSCI 591E) were given the option of receiving the course on CD as a CD-MANIC 5-CD box set or on pre-recorded videotape. Of the 22 students enrolled in the course, 8 or 36% chose to receive the CD version, 2 from VIP and 6 from NTU [8].

Following the successful launch of CD-MANIC over the Summer, Computer Networks was once again offered to VIP students in the Fall of 2001. In this semester, VIP was able to include the following as part of the Computer Networking course listing "Note: This course is available on videotape or CD ROM, please specify which option you prefer when registering for the course". Of the 21 students enrolled in the course 13 (2 from VIP and 11 from NTU) or 62% of enrolled students chose to receive the CD version.

Fall 2001 also saw CD-MANIC introduced at two other institutions where the textbook written

by Professor Kurose and included as part of the CD-MANIC discs was being used as the primary text for the course. In this case CD-MANIC was used as a supplement to the course, live instructors delivered in-class instruction.

Professor Parviz Kermani of the Westchester campus of Polytechnic University[9] offered a graduate course titled "Network Protocol". This course is offered in two programs at Polytechnic, one is a special program called Information System Engineering (ISE). This program gives an MS degree after 2 years (12 courses). The class meets for approximately 2 hours Friday/Saturday for every other weekend (14 classes in all). The students were all from industry and typical enrollment is 30-35 students. The students were mostly advanced practitioners, some at a higher level of technical management. In the Fall 2001 class, the CD-MANIC version of the course was demonstrated to the class by the instructor from his laptop computer and subsequently distributed to all students. Based on an informal inquiry by the instructor, most students said they did use the CD and all found the CD's to be very useful.

The second program at Polytechnic is one in which "Network Protocol" is offered as an evening class as part of Polytechnic's regular graduate program. The majority of students in this program are working towards an MS degree although some are pursuing PhD's. The students are primarily from industry, with some full time participants as well. The CD version was not made available to these students in the Fall but based on the positive experience with the ISE class it will be made available to them in Spring 2002.

"Computer Networking" on CD-MANIC was also trialed by Professor Ben O'Neal of North Carolina State University (NCSU) as part of his on-campus course. Some students were offered the option of using CD-MANIC on a trial basis in order for Professor O'Neal to gain experience with a few students prior to expanding the usage of CD-MANIC to 3 other campuses within the 16-campus North Carolina system.

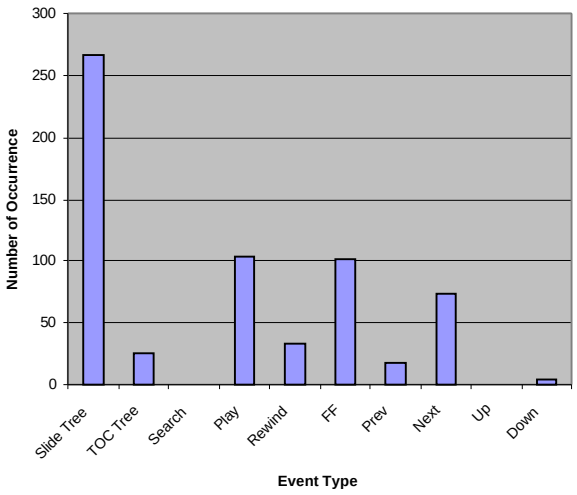
During Spring 2002 the CD-MANIC version of the course will be used at a total of four North Carolina campuses as an "e-learning" networking course. It will be distributed to approximately 32 Computer Science students at UNC-Wilmington taught by Professor Ron Vetter, 43 at North Carolina Agricultural and Technical State University (NCA&T) taught by Professor Ken Williams, 1 at UNC Asheville taught by Professor Dean Brock and 1 ECE student at NCSU taught by Professor Ben O'Neal. The latter two campuses have reduced numbers because they are offering an on-campus version of the course.

5. Conclusions from the Logged Data

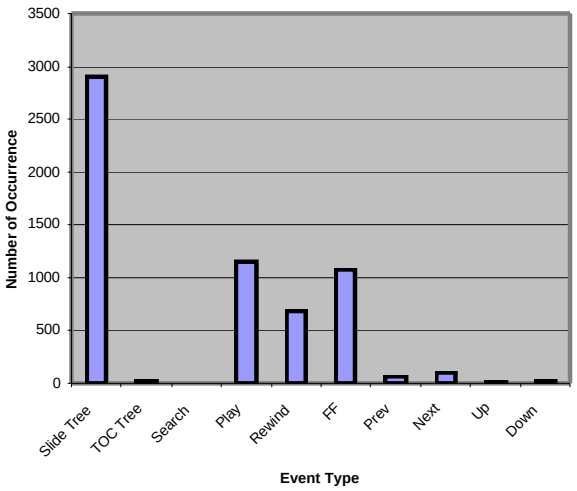
In this section, we show our results and conclusions from the logged data. The data was logged from the "Computer Networking" course offered through VIP/NTU in the Summer of 2001 and the Fall of 2001, the same course offered in NCSU and a course titled "Network Protocol" offered in Westchester campus of Polytechnic University.

Figures 1(a) through 1(d) shows the number of occurrence of navigation events for NCSU, VIP/NTU (Fall of 2001), VIP/NTU (Summer of 2001) and Westchester campus of Polytechnic University respectively. A navigation event occurs when the student performs an action that

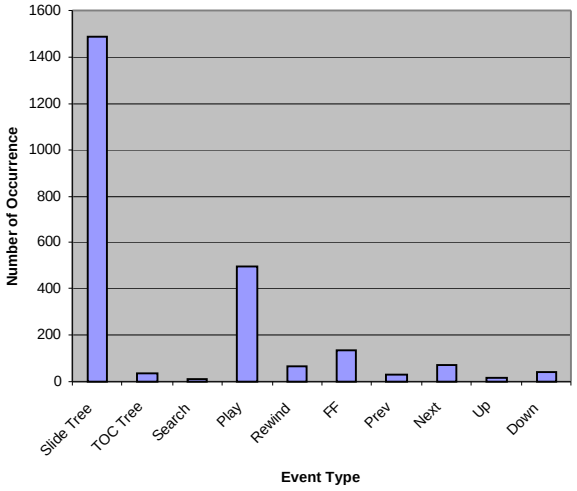
triggers CD-MANIC to log events related to Index type, Button type and Search type. The horizontal axis depicts the different navigation events. For example “Slide Tree”, “Table of Contents (TOC) Tree” and “Search” are the different index views that we can have. “Play”, “FF” and “Rewind” are the VCR style controls. “Prev” and “Next” are the slide navigation controls. “Up” and “Down” are the bullet navigation controls. “Slide Tree” and “TOC Tree” refer to events generated using the index and Fall in the event category of “Index Type”. “Search” belongs to the event category of “Search Type” and the remaining belongs to the event category of “Button Type”. The vertical axis depicts the number of times these events occurred.



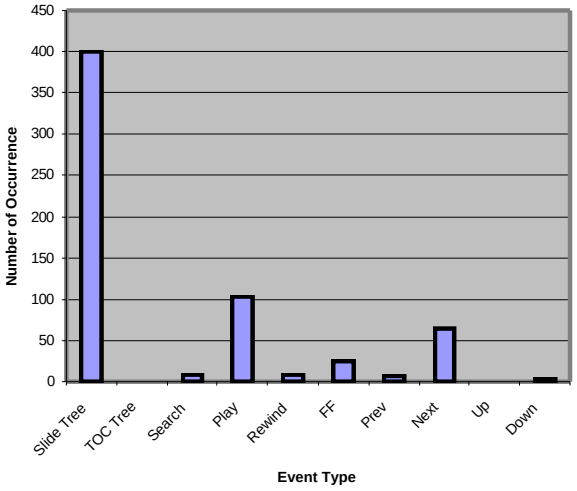
(a) NCSU



(b) VIP/NTU (Fall of 2001)



(c) VIP/NTU (Summer of 2001)



(d) Westchester campus of Polytechnic University

Figure 1. Number of occurrences for different navigation events.

From Figure 1, we infer that forward movement is 2 to 3 times more likely to occur than backward movement. “FF”, “Next” and “Down” buttons are considered to be related to forward movement as they progress in the forward direction through a course. Conversely, “Rewind”, “Prev” and “Up” buttons are considered to be related to backward movement.

The CD-MANIC search feature performs a brute force search through all the HTML slides that are a part of the course content. An interesting observation that we made from these figures is that CD-MANIC search feature is seldom used. This is evident from the extremely low occurrence of the “Search” event which in turn indicates that the search index view seldom appeared. In contrast, students access course contents by the slide index (i.e., indexing to a slide based on its title) which is shown by the high occurrence of the “Slide Tree” event. The low occurrence of the “TOC Tree” event indicates that students seldom accessed the TOC of the book. And hence we make an inference that the book was seldom used.

Figures 2 shows how much of the total Show Slide event is automatic and how much of it is triggered manually. The horizontal axis depicts the percentage of “Show Slide” event for automatic and manual slide show and the vertical axis depicts the different locations where CD-MANIC was used for this particular course.

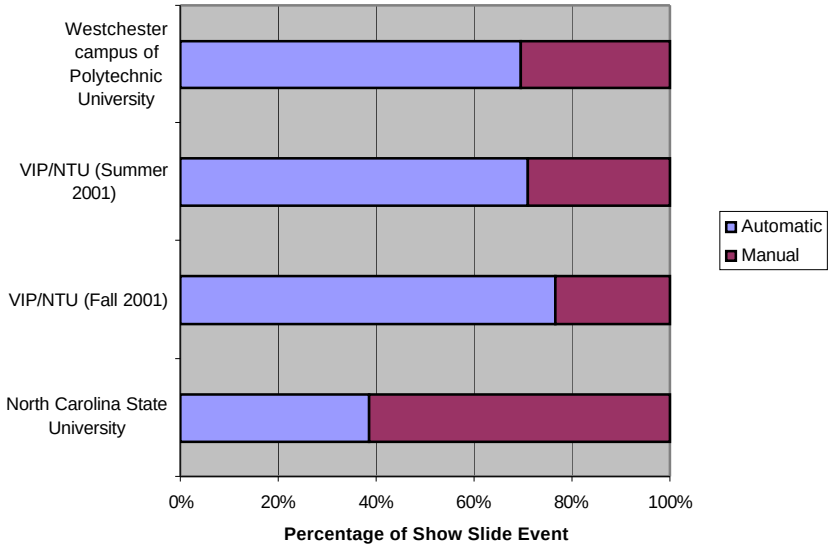


Figure 2. Show slide event as a percentage of automatic slide shows versus manual slide shows.

When the course is being played without any interruption, the slide changes automatically and the next slide is displayed. CD-MANIC makes use of the timing information to achieve this task and thereby synchronizes the slides with the video and audio. However, it is possible for the student to manually seek to a particular slide and then play the video corresponding to that slide. In this case, the student manually triggers the slide. From Figure 2, we see that except for the NCSU case, automatic slide changes occur more often than manual slide changes.

We also performed studies on distribution of audio/video playback over the total duration of all sessions in order to understand how much of significance the audio/video stream is in a

multimedia courseware. But before we go into these results, it is important to understand how we define a session. We define a session as a period of time in which event information is being recorded, where an event is any activity within the CD-MANIC application that is logged. The end of a session is determined by inactivity within a certain period of time. This period of inactivity is what Padhye and Kurose[6] define as being the Session Gap Threshold (SGT). We chose a value of 40 minutes for the SGT since, as seen in Figure 3, the slope of the curve is nearly 0 at approximately this time. In this figure, the horizontal axis represents the SGT value in minutes and the vertical axis represents the number of sessions for a given SGT value. Using this approach with an SGT value equal to 0, the number of sessions will be equal to the number of logged events and with an SGT value of infinity, the number of sessions will be equal to the number of logged students.

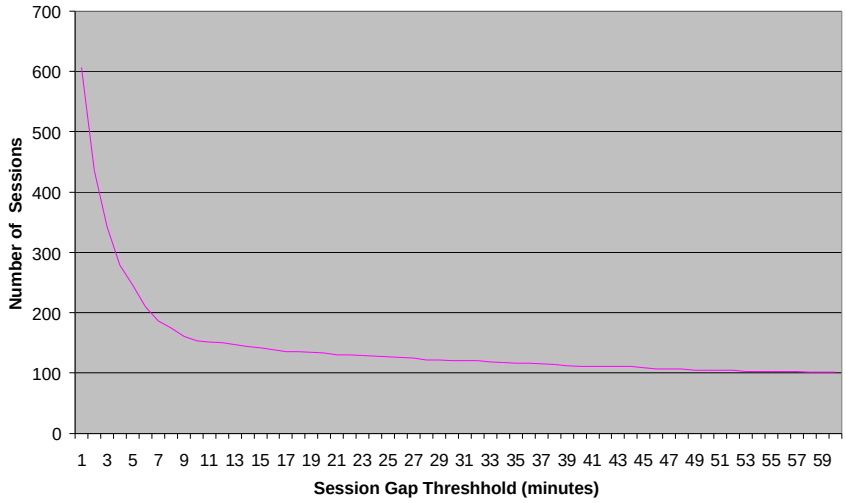


Figure 3. Number of sessions as a function of SGT.

Figure 4 shows the percentage of time during a session during which the audio/video was on and the percentage of time during which the audio/video was off. The horizontal axis depicts the percentage of the total session time during which audio/video was on and the vertical axis depicts the different locations where CD-MANIC was used for this particular course. For plotting this graph, we summed the session length over all students, summed the audio/video on time over all students and then took the ratio of these values.

For example, the total audio/video on time over all students in NCSU was 14,210 seconds and the total session time over all students was 37,580 seconds. Therefore, the total audio/video on time would be nearly 37.8% of the total session time. We chose this method as opposed to calculating the ratio of the audio/video on time and total session time and then averaging it over all students because in the latter case, the total session time for different students can be different and hence would lead to an inaccurate result. From Figure 4, we see that except for the NCSU case, the audio/video was on for more than 60% of the total session duration.

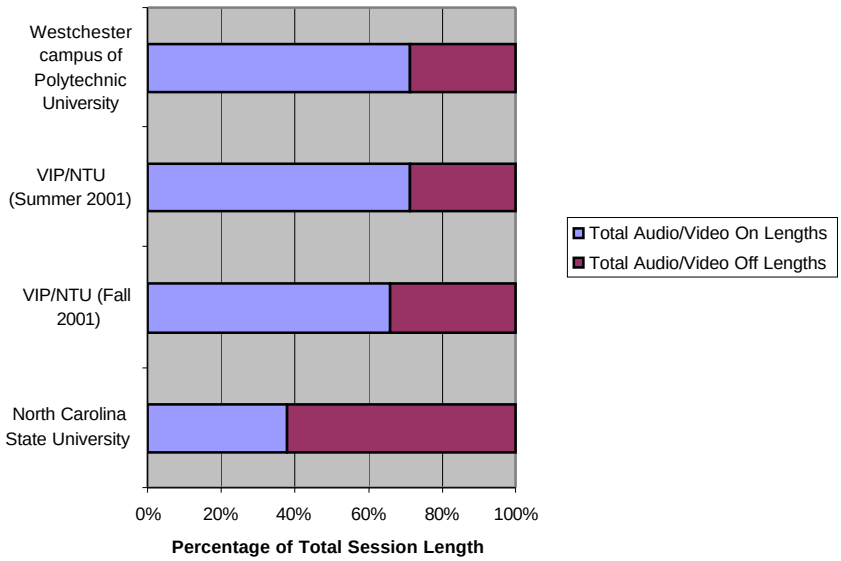


Figure 4. Division of total session length in terms of audio/video on versus audio/video off.

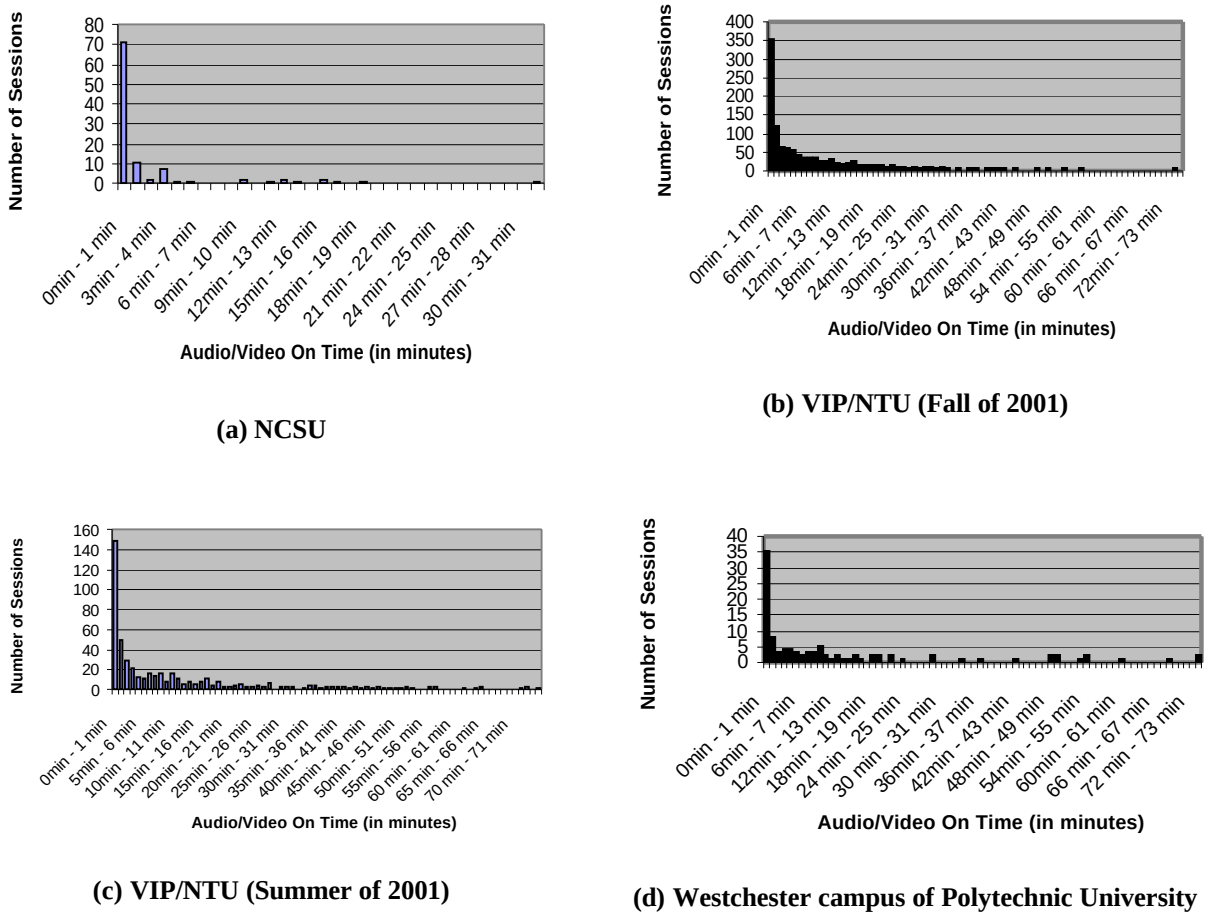
Figure 5(a) through 5(d) shows the distribution of the time for which audio/video was on for NCSU, VIP/NTU (Fall of 2001), VIP/NTU (Summer of 2001) and Westchester campus of Polytechnic University respectively. That is, it shows the distribution of the length of time between the start of an audio/video playout and time at which that audio/video playout stops. The horizontal axis depicts the time for which audio/video was continuously on and the vertical axis depicts the number of sessions.

From Figure 5, we can see that most students had the audio/video on continuously for well under 30 to 40 minutes and a large number of them had it for less than 10 minutes. This indicates that most students, after pressing the Play button, stop the audio/video within a relatively short duration. In other words, most students viewed material in short-term, highly-interactive modes as opposed to viewing them in long-term, continuous play modes. From this, we can infer that the CD-MANIC system is used in an extremely interactive manner and that very few students use the system as "couch potatoes".

In addition to tracking student behavior by logging data, we also conducted an online survey of students at the end of each course. We conclude this section with a few anecdotal results from that survey. First, students indicated an overall high level of satisfaction with the system, with the ability to access materials by computer (at home, at work, while traveling) being a major advantage. Students overwhelmingly noted that CD-MANIC's audio was superior to that of VHS tapes. While most students indicated that CD-MANIC's video was as good as, or better than, VHS tapes, a few students indicated that they felt the quality of VHS video was superior. No student indicated an overall preference for traditional VHS tapes over CD-MANIC. We also noted that the addition of an electronic version of the book did not seem to add appreciable value. No student indicated that having an electronic copy of the book available via CD-MANIC would cause them to not purchase a hardcopy of the textbook.

6. Conclusions and Future Work

In this paper, we have provided results from an empirical study of student interaction with CD-based multimedia courseware delivered to different locations namely, North Carolina State University, University of Massachusetts Amherst and Video Instructional Program/National Technological University. As mentioned earlier, this paper does not evaluate improvement in student learning. From our results, we infer that while navigating through a course, forward movement is 2 to 3 times more likely to occur than backward movement. We infer that the search feature was seldom used. In most cases, the audio/video was on for more than 60% of the total session length. We also infer that the CD-MANIC system is used in an extremely interactive manner and that very few students viewed the course in long-term, continuous play modes. We also point out two important anecdotal results that were obtained from online surveys: (i) no student preferred VHS tapes to CD, and (ii) no student said that given an electronic copy of the textbook, they would not buy a hard copy of the same. From this we conclude that CDs are attractive but hard copy textbooks still play an important role.



(a) NCSU

(b) VIP/NTU (Fall of 2001)

(c) VIP/NTU (Summer of 2001)

(d) Westchester campus of Polytechnic University

Figure 5. Audio/Video on length distribution.

We expect a lot of work aiming at developing future versions of CD-MANIC which more closely meet different student's needs. One among them is the development of a quizzing module

for student self-assessment. We also have 5 other courses from various disciplines which will be offered in Spring 2002. One significant change that we made based on the logged data was redesigning the interface to make the search feature more visible. The extremely low usage of the search feature can be attributed to the fact that the search button was buried in our earlier interface layout and hence most students probably were not even aware of such a feature. We have redesigned the student interface and expect to get very different log results in the future for searching.

Acknowledgement

We would like to acknowledge the support of the National Science Foundation through grants EIA-9502639, EIA-9979833 and EIA98-12589, and the support of the Center for Real-Time, Intelligent Complex Computing Systems at the University of Massachusetts Amherst.

Bibliography

1. G. Abowd, J. Brotherton, J. Bhalodia,"Classroom 2000: A System for Capturing and Accessing Multimedia Classroom Experiences",*Proc. of CHI '98 Demonstration Paper, 1998*.

2. P. Yeh, Bih-Horng Chen, M. Lai, and S. Yuan ,"Synchronous Navigation Control for Distance Learning on the Web", *Proc. of Fifth International World Wide Web Conference, 1996.*

3. Su-Shing Chen,"Linking User-Learner Needs and Behavior to Digital Library Design",*Proc. of Workshop on Digital Libraries, 1996.*

4. R. Shen, Y. Tang , T. Zhang, "The Intelligent Assessment System in Web-based Distance Learning Education ",*Proc. of Frontiers in Education Conference, 2001*.

5. G. Hislop, "Does Teaching Online Take More Time?", *Proc. of Frontiers in Education Conference, 2001*.

6. J. Padhye, J. Kurose, "An Empirical Study of Client Interactions with a Continuous-Media Courseware Server",*Proc of Network and Operating System Support for Digital Audio and Video, 1998*.

7. Video Instructional Program of University of Massachusetts, Amherst, *http://www.ecs.umass.edu/vip/*

8. National Technological University, *http://www.ntu.edu/*

9. Westchester campus of Polytechnic University, *http://www.poly.edu/west/*

10. Multimedia Systems Group, *http://vsp2.ecs.umass.edu/dvd/*

11. RIPPLES Group, *http://ripples.cs.umass.edu/*

12. BMRC Lecture Browser, *http://bmrc.berkeley.edu/frame/projects/lb/index.html*

13. Just In Time Lectures, *http://www.jitl.cs.cmu.edu/*

WAYNE BURLESON is an associate professor in the Department of Electrical and Computer Engineering at the University of Massachusetts Amherst. He obtained his PhD from University of Colorado in 1989. He is the leader of the Multimedia Systems Group[10] at the Department of Electrical and Computer Engineering and has developed several CD-MANIC courses. He also performs research in VLSI and DSP.

WENDY COOPER is a project manager for the RIPPLES[11] project at the Department of Computer Science at the University of Massachusetts Amherst. She obtained a M.Ed. in Science Education from the University of Massachusetts Amherst and a B.S.B.A. in International Business from The American University.

JAMES KUROSE is a Professor in the Department of Computer Science at the University of Massachusetts Amherst. He received his PhD from Columbia University. His research interests are in computer networks and multimedia systems. He is a Fellow of the ACM and IEEE. His course is profiled in this paper.

SANTHOSH THAMPURAN is a graduate student in the Department of Electrical and Computer Engineering at the University of Massachusetts, Amherst. He is a research assistant for the Multimedia Systems Group[10] as well as the RIPPLES[11] project at the Department of Computer Science at the University of Massachusetts Amherst. He obtained his Bachelor of Technology (Honors) degree from the Indian Institute of Technology, Kharagpur.

KEN WATTS is a senior software engineer for the RIPPLES[11] project at the Department of Computer Science at the University of Massachusetts Amherst. He obtained his MS and BS degrees in Computer Science from the University of Massachusetts Dartmouth.