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Interface and evaluation

Usability study of digital libraries: ACM, IEEE-CS, NCSTRL, NDLTD

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Abstract. If digital libraries are to be used effectively, their user interfaces should be tested and enhanced. We observed 48 participants as they worked with the following digital libraries: ACM, IEEE-CS, NCSTRL, and NDLTD. We discuss how the features of these digital libraries influence the subjects' efforts to perform search and retrieval tasks. Data analysis indicates that the IEEE-CS digital library was rated the best overall and NDLTD had the best search time. We present user recommendations and propose a taxonomy of features that we believe are essential for the design of future digital libraries. Noteworthy is the observation that users' judgements on the importance of different features varied widely between the beginning and end of their test sessions.

Key words: Usability – Performance – Search and retrieval – Taxonomy – Evaluation

1 Introduction

Digital libraries, which include collections of information that are both digitized and organized, extend many of the capabilities of traditional libraries [6]. Yet, if digital libraries are to be used effectively, research must focus on enhancing the utility of their user interfaces [5]. Our objective was to identify specific characteristics that influence the effectiveness (ease of use), likability, learnability, and usefulness of digital libraries. This study, conducted and originally submitted for publication in 1997, has revealed particular strengths and weaknesses of the digital libraries we considered. We hope that our findings will contribute to the knowledge base for the design of future digital libraries, and hence hasten the emergence and evolution of desktop access to scholarly information and world knowledge. In our study, we focused on four digital libraries: ACM, IEEE-CS, NCSTRL and NDLTD[1], selected in part because of convenient access, the ability to view full-text articles, and relevance to computer science. To increase the applicability of our findings, we chose systems with a variety of distinguishing features, as shown in Table 1.

The Association for Computing Machinery's (ACM) digital library (from `http://www.acm.org`) was launched in 1997. It provides online access to the full-text of ACM journals, magazines, and conference proceedings since 1991. It also contains tables of contents for 19 journals since 1985, tables of contents for more than 400 volumes of conference proceedings, bibliographic reference pages for all articles in the tables of contents, and functionality for free text search. The Institute of Electrical and Electronics Engineers Computer Society (IEEE-CS) digital library contains all issues of 17 of the society's magazines and transactions from 1995 to the present. This library also was launched in 1997. The collection is viewable and full-text searchable with standard Web browsers. The library can be accessed from `http://www.computer.org`.

The Networked Computer Science Technical Reference Library (NCSTRL) compiles technical reports of leading-edge research from more than 100 academic departments and research laboratories around the world. Since its inception in 1994, the NCSTRL system has grown rapidly and is being used as a testbed for experimentation with digital library technology. It can be accessed from `http://www.ncstrl.org`.

The Institute of Electrical and Electronics Engineers Computer Society (IEEE-CS) digital library contains all issues of 17 of the society's magazines and transactions from 1995 to the present. This library also was launched in 1997. The collection is viewable and full-text search-

[1] Acronyms and descriptions follow in the text.

Table 1. Features distinguishing the libraries

Feature	ACM	IEEE-CS	NCSTRL	NDLTD
Organization	Centralized	Centralized	Distributed	Distributed
Distribution	By publisher	By publisher	By federation	By federation
Type of work	Journals, Proceedings	Journals, Proceedings	"Gray literature"; requests	"Gray literature", theses
Format	HTML, PDF, PS	HTML, PDF	HTML, PS	PDF, HTML (abstracts only)

able with standard Web Browsers. The library can be accessed from `http://www.computer.org`.

The Networked Digital Library of Theses and Dissertations (NDLTD) aims to increase the availability of student research for scholars, and to advance digital library technology. It also makes the submission and handling of theses and dissertations less costly, more efficient, and preserves them electronically. NDLTD's collection home page is `http://www.theses.org`.

2 Methods

Initially, we explored the four digital libraries to formulate user tasks that were of similar difficulty for each library. We devised four tasks in this way for each library that primarily involved searching and retrieving articles. A copy of the user tasks can be found in Appendix A.

2.1 Subjects

The participants in this study were 48 Virginia Tech students, 39 male and 9 female. 38 were graduate students in Computer Science, 8 were undergraduate students, and two were from other graduate studies. Based on the pre-questionnaire given to all participants, subjects were classified into two user groups: experienced and novice. Experienced users were those who had previously used at least one of the digital libraries being studied. According to this classification, there were 21 experienced and 27 novice participants. A report of the differences between these two user classes is covered in detail in the results section.

2.2 Experimental setup

To minimize the effects of external parameters such as network traffic, we conducted all experiments between the hours of 10 am and 2 pm over a two-week period during October 1997. We carried out our experiments using Netscape Navigator Gold^{TM}3.1 browser on a Pentium PC. We used the IDEAL system [4], developed at Virginia Tech's HCI Laboratory, to capture participant interactions with the digital libraries.

The IDEAL system software is spreadsheet-like and housed on a DECstation that synchronizes a log of observer comments, user behavior recorded on a video camera, and screen activity captured with a scan converter. The system captured details of the users' interaction. The evaluators were able to view simultaneously the user and their activities as they explored the libraries. The IDEAL software allowed the evaluators to create a data session for each participant in which critical incidents were recorded as they occurred.

2.3 Procedures

After signing a consent form, subjects began their session by completing a pre-questionnaire (see Appendix B). We used the pre-questionnaire to assess their prior exposure to digital libraries, and to determine the features they expected in a digital library. A summary of the results obtained from the pre-questionnaires is presented in Appendix D.

To account for the effect of learning, all orders of presentation of the four libraries were randomly assigned the participants. In the testing room an oral briefing on tasks to be performed was given, including an overview of the equipment and software to be used during the evaluation. The subjects were briefed about communicating with the evaluators via the speaker/microphone equipment. A one-way window separated the testing room from the evaluation room. This enabled evaluators to observe the subject. Critical incidents were recorded with time-synchronized video and audio supplemented by evaluators' annotations using the IDEAL software.

The participants each were asked to complete all tasks for all four systems with no time restrictions. The evaluators inquired about the subjects' perceptions of the interface after tasks were completed. User perceptions have been incorporated in the user recommendations (Sect. 3.3). The average time for a four-system session was 37 minutes 26 seconds.

Upon session completion, the user was given a post questionnaire (see Appendix C) to reassess the features that they perceived as important considering their recent experience. We also asked the users to rate the libraries with regard to the following considerations: easiest to

search, browse, read, learn, and easiest overall. A summary of the results obtained from the post-questionnaires is presented in Appendix D.

3 Results

In our testing of digital libraries, we were investigating the ease of use of those libraries. We also were interested in user recommendations for the construction of future digital libraries.

The results were similar between the novices and the experienced users except in the case where they had prior knowledge of that specific library. Once the novice users learned the method to accomplish the first task, their times were comparable to their experienced counterparts. The first three tasks for each of the libraries were very similar. Upon completing the first task, the next two tasks were easily accomplished.

We performed a non-parametric data analysis of user post surveys. Based on frequency counts from the post-questionnaires, 43% of users selected IEEE-CS as the "best overall" digital library. ACM was rated second by 25% of the users, followed by NDLTD with 19% and NCSTRL with 12%. These results are depicted in Fig. 1.

3.1 Features and ratings

In the pre- and post-questionnaires, we asked users to rank the following features:

- Breadth of coverage
- E-mail notification
- Deep historical content
- Full-text search
- Depth of coverage
- Search in context
- Easily readable online text
- Timely content
- Easily readable printed text
- Visual similarity to printed version

In comparing the results from the pre- and the post-questionnaires, we note that after participating in the study, ratings changed in most cases. Appendix D and E show respective pre- and post-questionnaire results. Relative to pre-test ratings, the post-test ratings valued:

- Breadth of coverage: less, with 13 instead of the original 21 considering this a top priority;
- Deep historical content: more, especially at lower priorities, indicating that users would like older items too;
- Depth of coverage: shifted slightly to lower priorities, indicating that detailed content was at least somewhat present;
- Easily readable/understandable online text and graphics: more, especially at low priorities, indicating difficulties with the online materials;
- E-mail notification: shifted to lower priorities (so the value of routing new results appears less);
- Search in context: increased in interest, shifted to higher priority, so perhaps users saw the value of more powerful searching;
- Timely content: increased in interest, but shifted to lower priorities, so perhaps users saw it as valuable but not crucial;
- Visual similarity to printed version: increased in interest but shifted to lower priorities, indicating that users saw this as relatively less important.

Similarly, in comparing pre- and post-questionnaires regarding search criteria, we note that keyword searching was viewed most important, though less so after the session. Title and then author searching were viewed next most important, both increasing in priority after the session. Search by citation and year were viewed least important, even less so after the session. This corresponds to the observation that users of digital libraries learn more about searching through practice, including that title and author searching have a role supplementing keyword search. Similarly, experience with digital libraries led to decreases in priority in plain text and bitmap displays, with stable interests in PDF and HTML (the preferred form, possibly due to familiarity with WWW).

Regarding ease of use, five questions were asked in the post-questionnaire. Table 2 summarizes these results. The weighted average indicates the top four participant's ratings, with lowest value being best. Thus, for the first row of the table, $86 = 1*12 + 2*10 + 3*10 + 4*8$. Bold face indicates best score, based either on weighted average or achieving a rating of 1. Clearly, ACM and IEEE-CS are rated better than the other two systems.

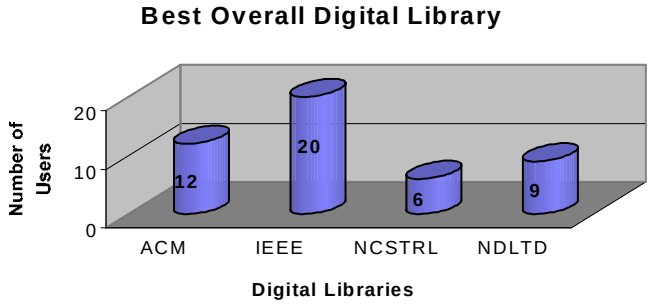


Fig. 1. Best overall digital library

3.2 Search times and search errors

The average session time across all four libraries varied from 6 minutes 23 seconds to 11 minutes 55 seconds. NDLTD had the smallest average search time, 6 minutes and 23 seconds. We attribute this result to the size of the collection at the time, approximately 500 theses and dissertations, and the fact that response was rapid for this on-campus database. The comparison of session search

Table 2. Ease of use results

			Number of participants who selected:			
	System	Weighted average	Rating 1	Rating 2	Rating 3	Rating 4
Easiest to Read	ACM	86	12	10	10	8
	IEEE-CS	101	17	7	10	10
	NCSTRL	105	7	15	12	8
	NDLTD	101	12	11	9	10
Easiest to Learn	ACM	100	8	15	14	5
	IEEE-CS	91	23	9	6	8
	NCSTRL	107	7	10	14	11
	NDLTD	113	10	12	9	13
Easiest to Browse	ACM	98	13	10	7	11
	IEEE-CS	104	11	12	11	9
	NCSTRL	103	13	12	10	9
	NDLTD	111	11	10	12	11
Easiest to Search	ACM	97	13	15	6	9
	IEEE-CS	88	21	10	5	8
	NCSTRL	108	7	13	13	9
	NDLTD	126	7	5	15	16
Easiest Overall	ACM	89	12	14	7	7
	IEEE-CS	91	20	5	11	7
	NCSTRL	105	6	16	9	10
	NDLTD	142	9	7	13	15

times is shown in Fig. 2. With the aid of the IDEAL system, the evaluators were able to observe the exact start and completion of tasks for a library. A one-way analysis of variance (ANOVA) on search times indicated significant differences among the digital libraries ($F(3147) = 27.96$, $p < .05$). Newman–Keuls Sequential Range Test was run as a follow-up. It showed that there were significant differences among the search times for NDLTD and each of the other libraries, and also significant differences between ACM and NCSTRL, and ACM and IEEE-CS ($p < .05$). Standard deviation was least with NDLTD (2.8), intermediate with NCSTRL (3.4) and ACM (3.9), and largest for IEEE-CS (4.3).

We defined an error as an incorrect type of search if the user followed an incorrect search path or structured the search query improperly. As for errors, IEEE-CS had the least average number of errors, 0.76, while NCSTRL

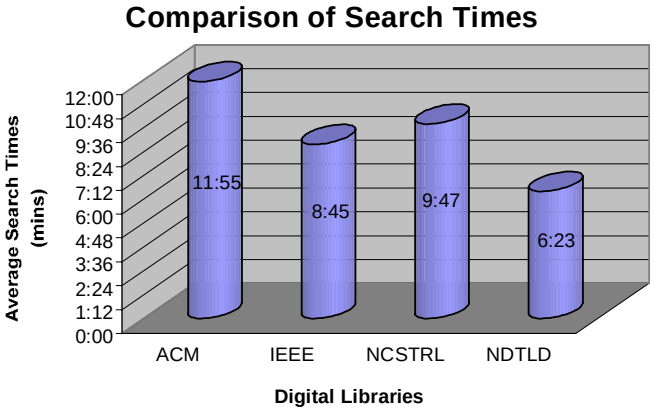


Fig. 2. Comparison of search times

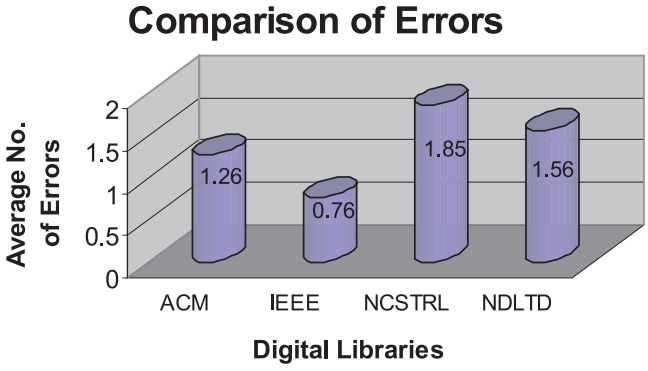


Fig. 3. Comparison of errors

had the highest, 1.85. Figure 3 shows the comparison of errors for the four digital libraries.

3.3 User recommendations

Based on user feedback from the post- questionnaires, a list of user recommendations was compiled. It includes the following points:

- Clear overview of digital library layout: Many users were often confused about the structure of the digital collection. In NDLTD the users were confused about the difference between "browse" and "search" links. In NCSTRL the users found it difficult to locate the "participating institutions" link which would lead them to a range of authors to browse. In several cases, the users incorrectly searched outside of the library, e.g., searched the ACM World Wide Web site not the ACM digital library. The IEEE-CS web site would allow the user to search their entire web site (by using the "search" link in the left frame) and also allow the users to search only in their digital library (link in the right frame), but the results returned in either case were the same;
- Facilities to filter search results and save queries for additional refinement: Users also wanted to view search results in various forms and save their queries. The queries then could be used later as a sort of search history and also further refined. This is similar to the results found in the Iodyne [8] study;
- Search criteria to accommodate both simple and advanced searches: Some users expressed an interest in the ability to perform both simple and advanced searches as they desired. A simple search restricted the user to keyword searches, typically using title and/or author. These searches usually returned only exact matches. An advanced search allowed the users to structure their query using numerous criteria, like the following: title, author, year, specific collection, keyword, or abstract. Advanced searches enabled the user to incorporate Boolean and wildcard expressions into their queries. Additional search criteria could also be added to the search to allow for the return of similar and/or related results;
- Fast searching and retrieval of documents: An efficient search engine also was considered an important feature.

4 Discussion

We examined the usability of four digital libraries. Participants were able to search and retrieve information from the various collections. In some cases, searching and retrieving were not easy tasks, especially the first tasks in the NDLTD and NCSTRL collections.

Based on the responses collected from the questionnaires, a majority of participants expect digital libraries to provide many of the features found in a traditional library. These features include a broad coverage of many topics, easily readable online text and graphics, full-text search, etc. (see Appendix D).

With regard to searching, many different opinions were expressed. Some users commented that the search interfaces were too complicated and distracting. Others complained that the ACM digital library provided too many search options. Some thought the interfaces were too simple, especially the IEEE-CS digital library interface. Users wanted to search by keyword, author, or title, and where appropriate by year, journal, and volume. The majority of users wanted search results presented as PDF, HTML, or plain text (see Appendix D). One participant suggested that a difficult search interface might discourage future use of the digital library – the participant was referring to the ACM interface.

To assist the user, good help facilities should be available [5]. Users had complaints about the help provided: NDLTD online instructions were not easy to understand, while many ACM and NCSTRL users consulted the online help multiple times in formulating their queries. Perhaps example queries on the search interface, such as those provided by the Envision and DeLIver [1] systems, would be helpful.

Many users became disoriented and frustrated while searching for information as the sites did not provide sufficient cues to guide the user's search. For example, in NDLTD the difference between search and browse was not obvious. In the NCSTRL digital library, finding a link to browse the collection of participating institution titles was time consuming. Users suggested more descriptive hyperlinks and additional information about these links particularly with regard to the NCSTRL digital library. This can be facilitated either with short explanatory information on the page or callout boxes (tool tips) when hovering over an area of the screen.

5 Future work

If digital libraries are to be used more in the future, additional research must be carried out to evaluate user needs and expectations. From our findings, we are constructing a taxonomy (see Table 3) of features that we believe are essential for the construction of an effective digital library. Currently, there are seven categories in the taxonomy. Our study included four digital libraries, but in our current taxonomy we also considered the DeLIver system, because we felt it possesses most of the features of an archetypical digital library. We will be adding additional features as we explore other digital libraries.

The features in Table 3 were derived from user feedback and evaluators' observations. Each digital library that we surveyed was judged by all the criteria within the taxonomy and rated by how well they satisfied each criterion.

Table 3. Taxonomy of features for designing digital libraries

Feature	ACM	IEEE-CS	NCSTRL	NDLTD	DeLiver
Clear overview	•	•			••
Search criteria for simple search	••	••	••	••	••
Search criteria for advanced search	••		•		••
Fast searching and retrieval	•	••	••	••	•
Example searches	•	•		••	••
Ability to download a fraction of the article				••	
Save queries for future Refinement					••

•• – Library has robust coverage of feature
• – Library supports the functionality minimally
– Library does not support functionality

We shared our results with staff involved in the various digital library projects investigated. Each has undergone considerable change since our study was completed. In particular, interface work on NDLTD has been considerably influenced by this investigation [7]. We plan further work on interfaces for NDLTD [2], MARIAN [3], Computer Science Teaching Center (see http://www.csct.org), and other digital library systems hosted at Virginia Tech.

Appendices

Appendix A: User tasks for digital libraries usability study

Please complete as many of the tasks below as possible. You should explore the digital libraries in the order indicated on your "strip". Bookmarks for the libraries can be found by clicking on the Bookmarks menu.

ACM

1. Find the abstract entitled "Integrality and Separability of Input Devices" in ACM Transactions in Computer-Human Interaction.
2. Find the abstract of "Clustering for Glossy Global Illumination" in ACM Transactions on Graphics.
3. Find the article, "The Next Date Crisis and the Ones After That" by Robert L. Glass in Communications of ACM.
4. Find the first article in Vol.12 of ACM Transactions of Information Systems and find its computing review.

IEEE-CS

1. Find the article "A Framework for Evaluating Software Technology" by Alan W. Brown.
2. Find the abstract of the article, "Comparison of Electrical Engineering of Heaviside's Times and Software Engineering of our Times".
3. Find the article, "Visualizing the dynamic behavior of Wonderland" in IEEE-CS Computer Graphics and Applications.
4. Find the subscription information for IEEE-CS Concurrency.

NDLTD

1. Find the listing of theses and dissertations for authors whose last name begins with C.
2. Find the thesis written by Fred L. Drake, Jr.
3. Find a dissertation from the Electrical Engineering department.
4. Find the abstract for the dissertation by Panela B. Teaster.

NCSTRL

1. Find the authors from the University of Virginia whose names begin with the letters A-C.
2. Find the documents written by Markus Michaelis at the Technical University of Munich.
3. Find the document, "Adapting Protocol to Massively Interconnected Systems" by Dr. Marc Abrams and Dr. Kafura of Virginia Tech.
4. Find all articles from Auburn University.

Please end your session by completing a post-questionnaire. *Thanks again for participating in this study!!*

Appendix B

Pre-test questionnaire

Thanks very much for agreeing to participate in this experiment. Our aim is to study the usefulness of several digital libraries. All of your personal data that we collect will be entirely confidential, viewed onl by the experimenters, and shared only as part of group results. But first, we would like to gather a bit of background information about you, so that we will be better able to interpret your use of and reactions to the digital libraries.

Gender: _____ Age:_____

Academic level (circle): Fr So Jr Sr Grad Major: _____

Please check the response that best represents your judgment.

Are you familiar with WWW search techniques (Yahoo, Lycos, Infoseek, etc.)?
Yes _____ No _____

Have you used any of the following digital libraries?
ACM:____ No. of hours:____
IEEE-CS:____ No. of hours:____
NCSTRL:____ No. of hours:____
NDLTD:____ No. of hours:____
Others (specify):_____ No. of hours:____

How are you most likely to use a digital library?
For research:____ For keeping current: ____ For both:____
Other:_____

Which of these features would be most important to you in a digital library?
Please rank the following features. (Indicating 1 for the most important and 10 for the least important.)

_____Breadth of coverage (many topics)
_____Deep historical content (i.e., going back more than 3 years)
_____Depth of coverage (detailed material on specific topics)
_____Easily readable/understandable online text and graphics
_____Easily readable/understandable printed text and graphics
_____E-mail notification of new articles
_____Full-text search
_____Search in context (only within titles for example)
_____Timely content (concurrent with print)
_____Visual similarity to printed version
_____Other (specify)_____

How would you like to search for information, indicating 1 for the most important method and 5 for the least important?
By year: ____ By author:_____ By title:_____
By keywords:_____ By citation:_____Others (Specify): _____

How would you like the search results to be presented?
PDF:_____ HTML:_____ Plain Text:_____
Bitmap page images with zoom in/out:____ Others (Specify):_____

Please briefly describe what you believe a digital library should provide:

Appendix C

Post-test questionnaire

Thanks again for participating in this experiment. Now that you are more familiar with digital libraries, please take the time to respond to these questions.

Please check the response that best represents your judgment.

Considering your new experience with digital libraries, please rank the following features.
(Indicate 1 for the most important and 10 for the least important)
_____Deep historical content (i.e., going back more than 3 years)
_____Depth of coverage (detailed material on specific topics)
_____Easily readable/understandable online text and graphics
_____Breadth of coverage (many topics)

_____Easily readable/understandable printed text and graphics
_____E-mail notification of new articles
_____Full-text search
_____Search in context (only within titles for example)
_____Timely content (concurrent with print)
_____Visual similarity to printed version
_____Other (specify)_____

Explain why you ranked the features as indicated above. How do these features contribute to your utilization of the library?

How would you like to search for information, indicating 1 for the most important method and 5 for the least important?
By year: ____ By author:_____ By title:_____
By keywords:_____ By citation:_____Others (Specify): _____

How would you like the search results to be presented?
PDF:_____ HTML:_____ Plain Text:_____
Bitmap page image with zoom in/out:____ Others (Specify):_____

Please fill in the following table regarding the 4 digital libraries. For each characteristic, indicate 1 for the best and 4 for the worst.

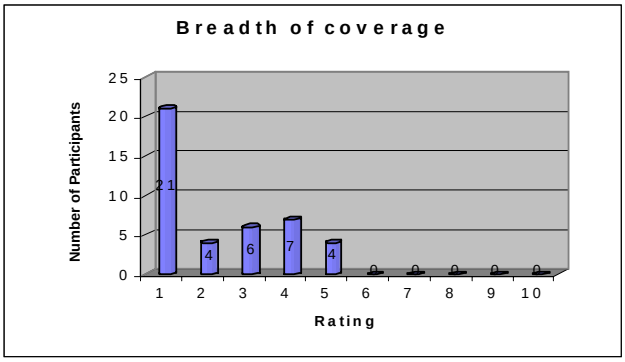
	ACM	**IEEE-CS**	**NCSTRL**	**NDLTD**
Easiest to search				
Easiest to browse				
Easiest to read				
Easiest to learn				
Easiest overall				

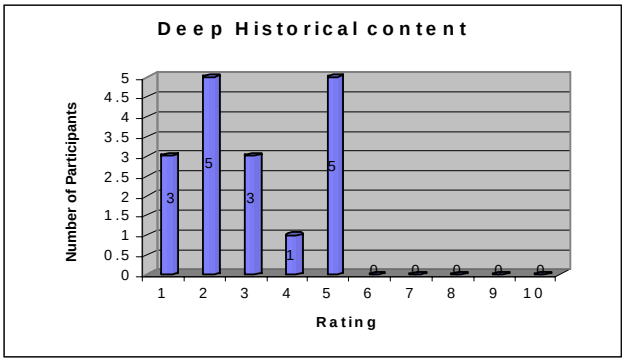
Based on your experience, please provide any additional comments regarding the usability of digital libraries.

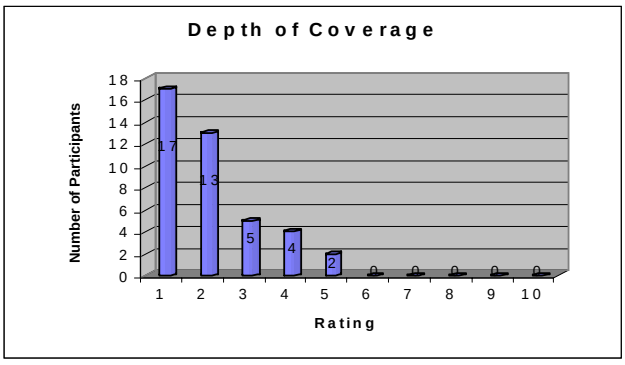
Appendix D

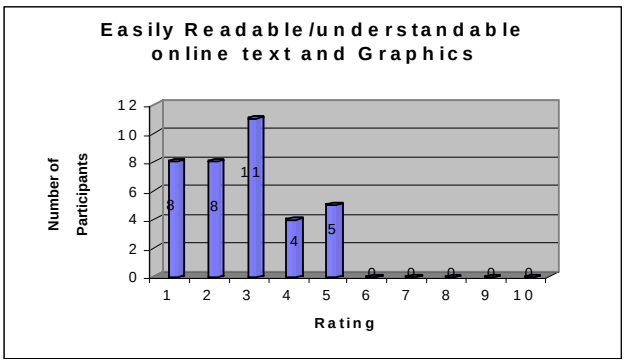
This appendix is organized so that you can compare pre- and post-questionnaire results regarding the features that were rated by our participants. The rating scale ranges from 1 to 10, with one indicating the most important and ten indicating the least important feature.

Pre-questionnaire results

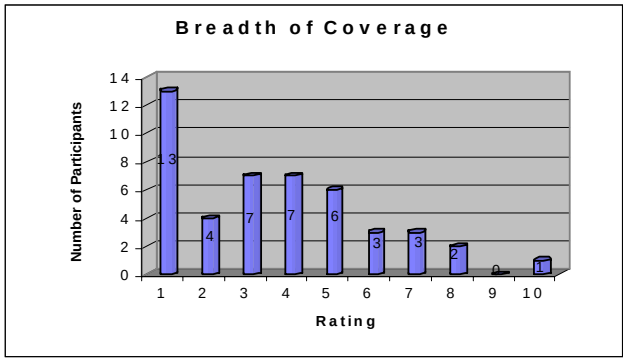


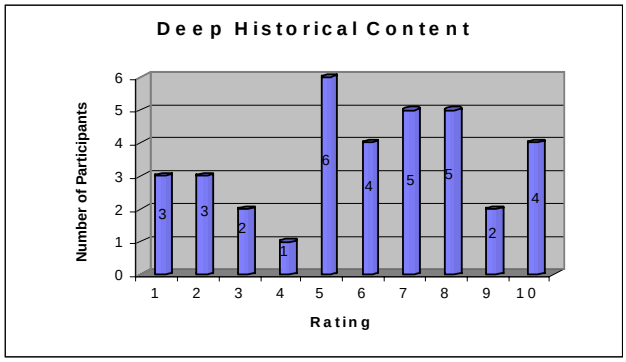


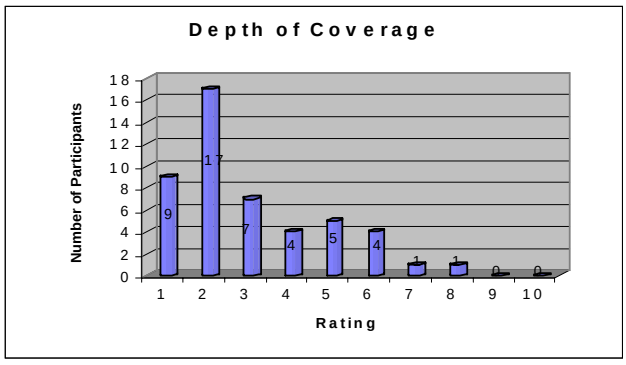


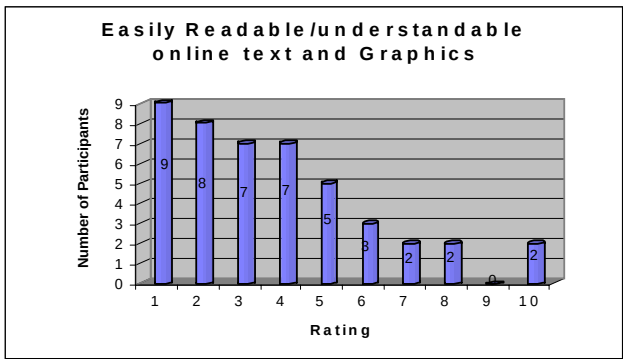


Post-questionnaire results

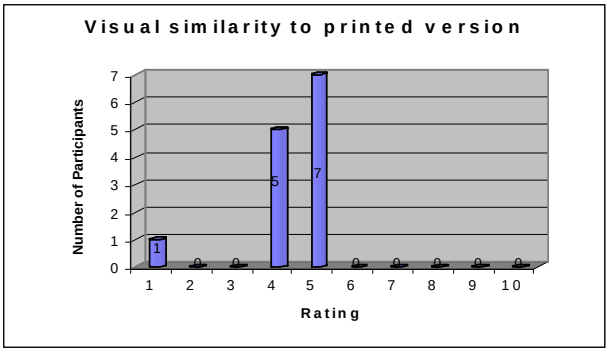


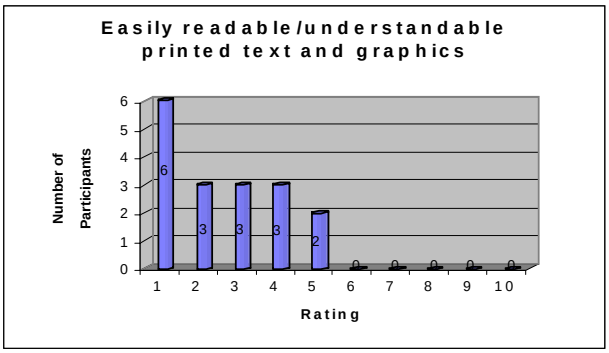


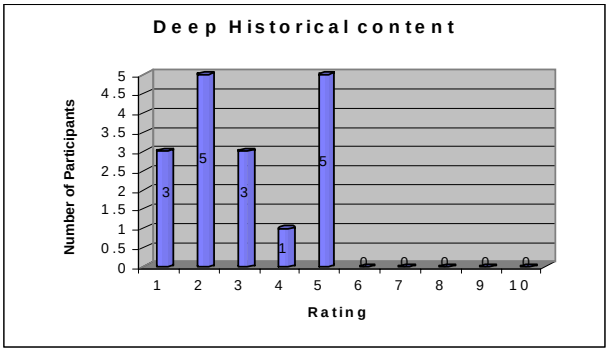




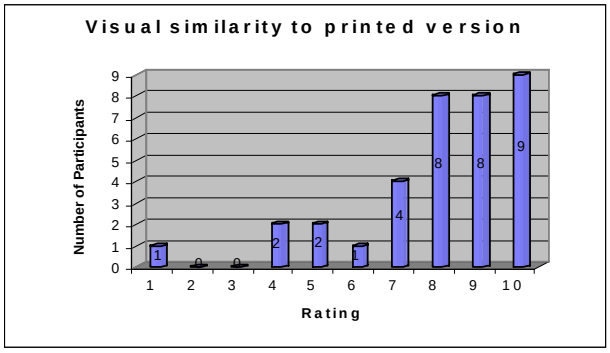
Pre-questionnaire results

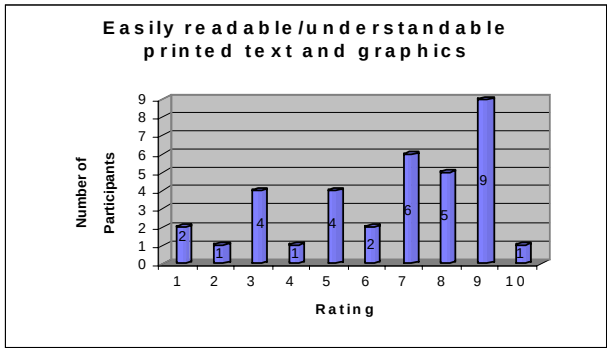


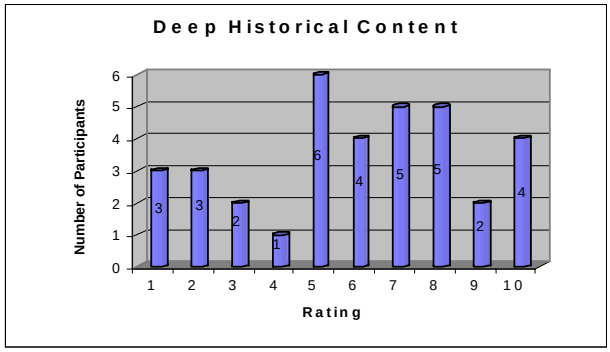




Post-questionnaire results



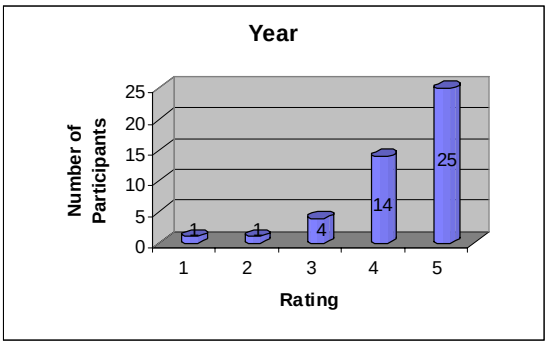


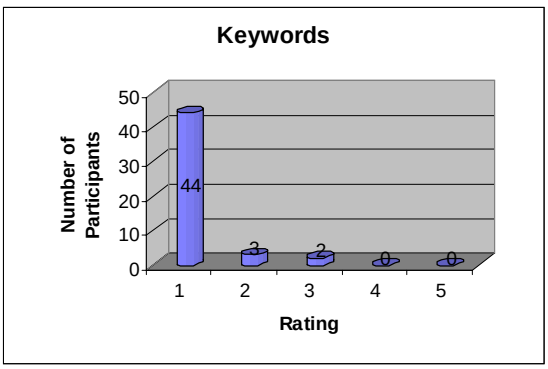


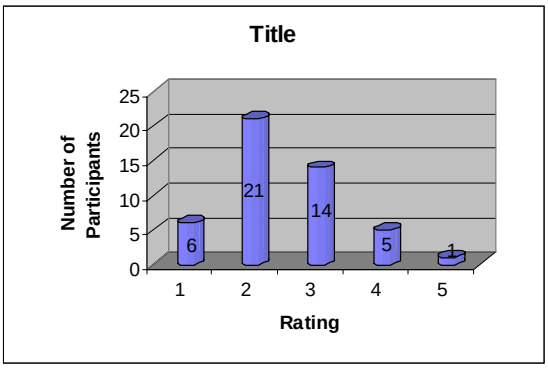
Appendix E

This appendix is organized so that you can compare pre- and post-questionnaire results regarding the participants preferred method of searching. The rating scale ranges from 1 to 5, with one indicating the criteria is very important and five indicating that the criteria is of little importance.

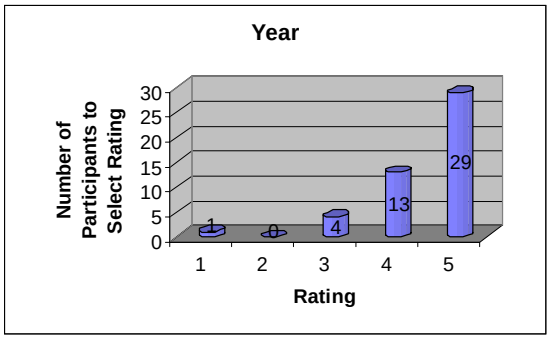
Pre-questionnaire results

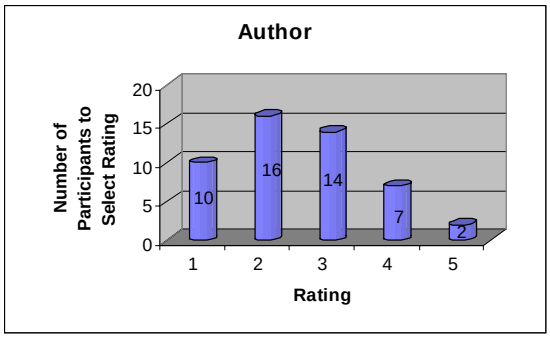


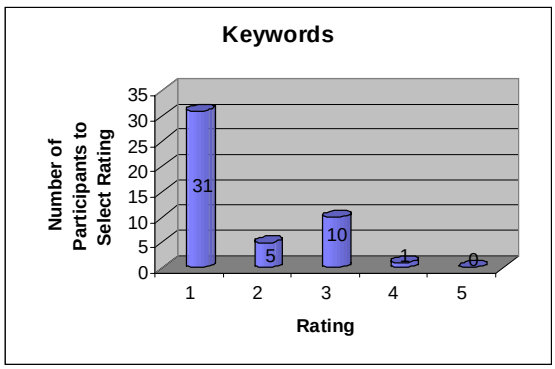


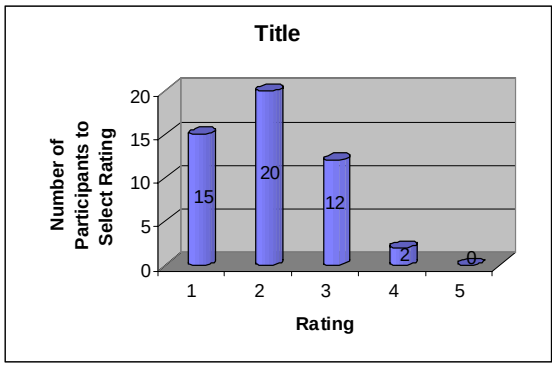


Post-questionnaire results



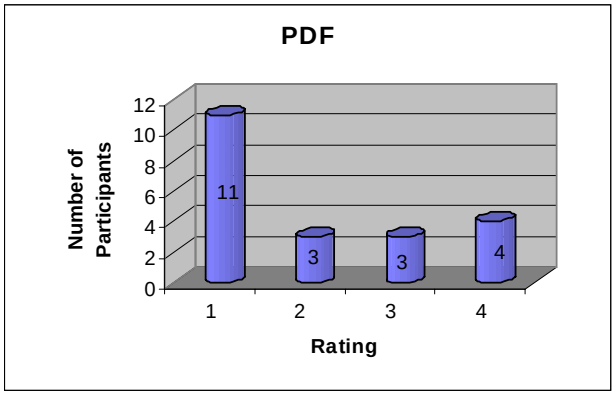


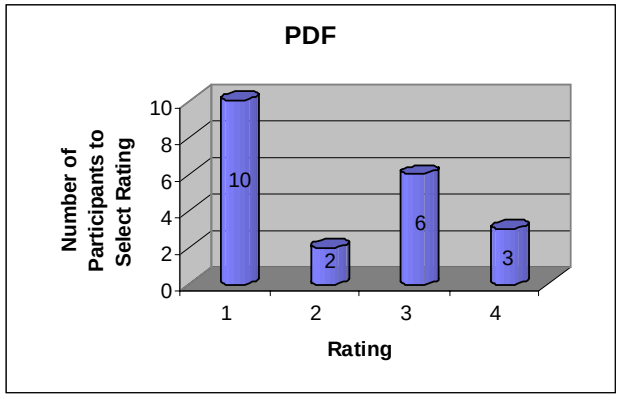


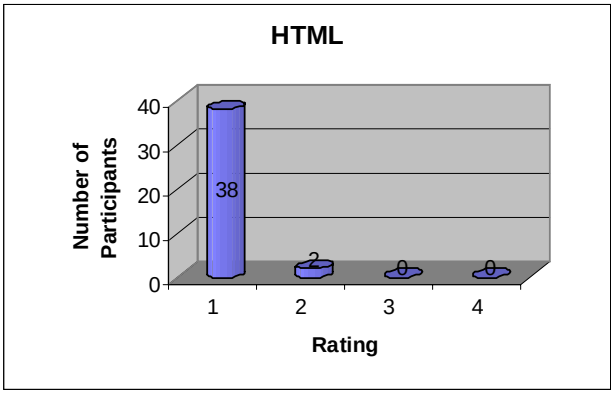


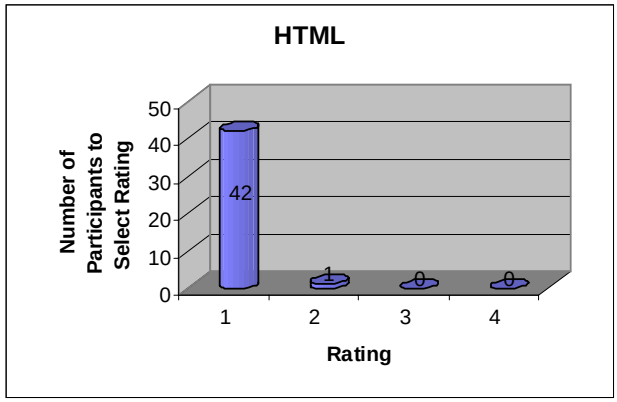
Pre-questionnaire results
Preferred presentation medium

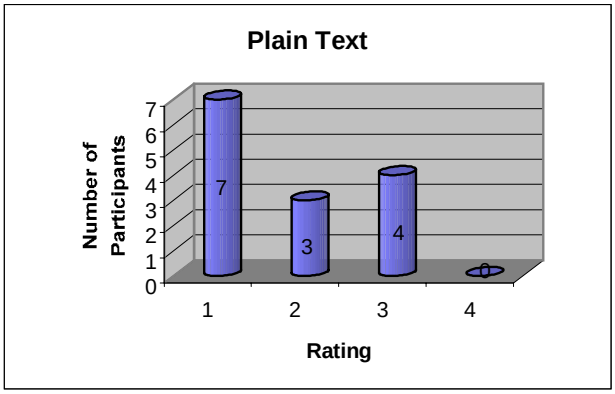
Post-questionnaire results

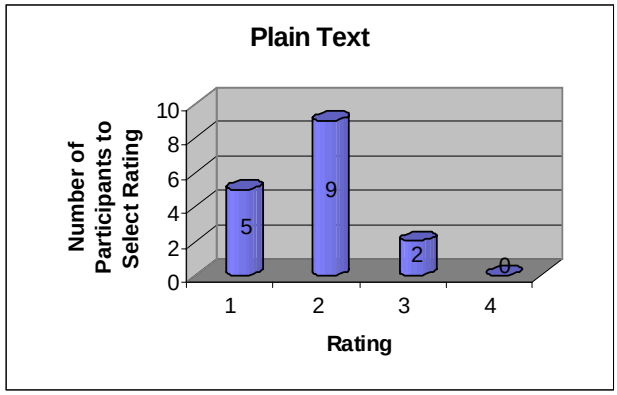


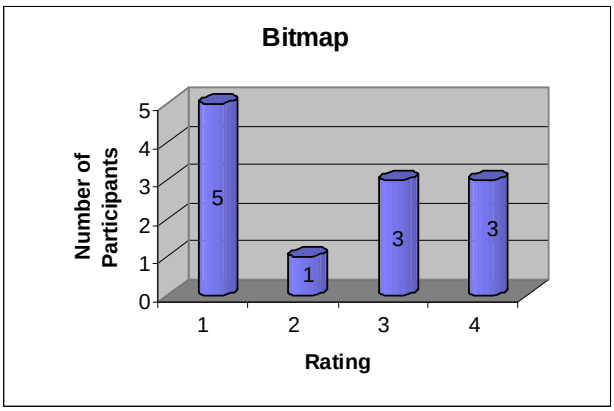


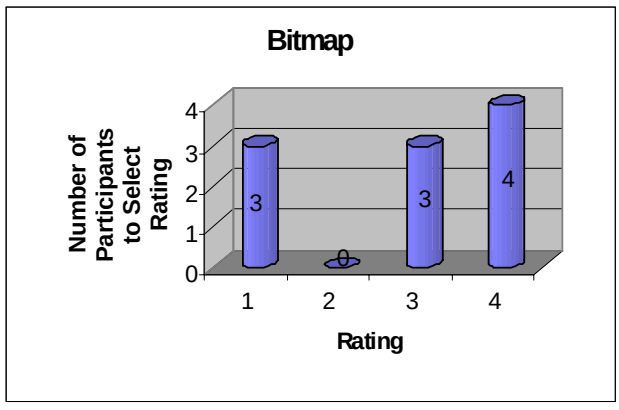




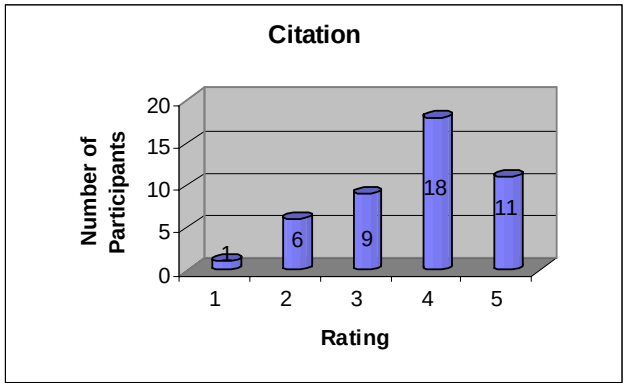




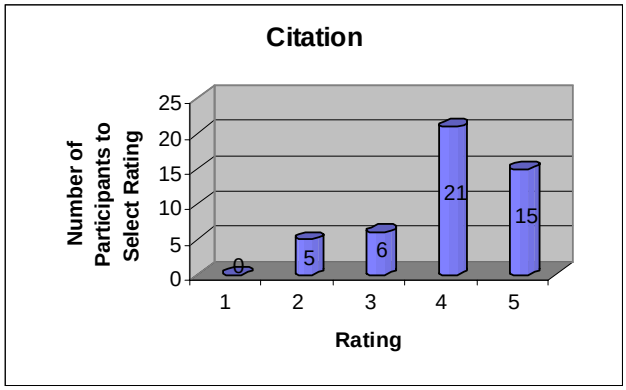




Pre-questionnaire results
Preferred method of searching



Post-questionnaire results



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